THE RESOURCES AGENCY OF CALIFORNIA

Department of Water Resources

BULLETIN No. 74-2

RECOMMENDED MINIMUM WATER WELL CONSTRUCTION AND SEALING STANDARDS FOR THE PROTECTION OF GROUND WATER QUALITY ALAMEDA COUNTY

Preliminary Edition

DECEMBER 1962

EDMUND G. BROWN
Governor
State of California

WILLIAM E. WARNE
Administrator
The Resources Agency of California
and Director
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THE RESOURCES AGENCY OF CALIFORNIA
DEPARTMENT OF WATER RESOURCES
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January 2, 1963

Honorable Edmund G. Brown, Governor
and Members of the Legislature of
the State of California

San Francisco Bay Regional Water Pollution
Control Board

Gentlemen:

I am pleased to transmit to you Bulletin No. 74-2 of the Department of Water Resources, entitled "Recommended Minimum Water Well Construction and Sealing Standards for the Protection of Ground Water Quality, Alameda County." The investigation was conducted under authority of Section 231 of the Water Code and at the request of interested agencies operating in the county.

This is one of a series of reports designed to formulate and recommend water well construction and sealing standards for particular localities of the State where regulation is deemed necessary for the protection of ground water quality. In Alameda County, where no such regulation exists, many water wells, which have been constructed improperly or sealed inadequately when abandoned, are contributing to quality impairment of ground water by allowing interchange of water between aquifers. The report concludes that water well construction and sealing standards must be employed. The standards presented are based on physical conditions and well construction practices found in Alameda County, and supplement the minimum standards presented in Bulletin No. 74, entitled "Recommended Minimum Well Construction and Sealing Standards for the Protection of Ground Water Quality, State of California."

The report recommends that the San Francisco Bay Regional Water Pollution Control Board urge adoption and enforcement, by Alameda County, of water well construction and sealing standards. The report also recommends continuation of the investigational work leading to the identification and correction of existing improperly constructed and abandoned water wells.

Because of the importance of protecting water quality in the ground water basins covered in this report, it is requested that Alameda County keep the San Francisco Bay Regional Water Pollution Control Board and this department informed of progress in the implementation of these recommendations.

Sincerely yours,

William E. Warne

Director

ACKNOWLEDGMENTS

Valuable assistance and data used in this investigation were contributed by public and private agencies and individuals. This cooperation is gratefully acknowledged.

We are appreciative of the assistance of the many water well drillers in Alameda County who provided information pertaining to water well construction and sealing. We also are grateful to the California State Department of Public Health, Bureau of Sanitary Engineering, for assistance in the collection of field data and in preparation of standards, pertaining mainly to the sanitary aspects of well construction.

Special mention is also made of the helpful cooperation of the following:

United States Geological Survey, Ground Water Branch and Quality of Water Branch

San Francisco Bay Regional Water Pollution Control Board

Board of Supervisors, County of Alameda

Alameda County Flood Control and Water Conservation District

Alameda County Water District

East Bay Municipal Utility District

California Water Service Company

Many of the water analyses used in the preparation of this report were made by the United States Geological Survey, Quality of Water Branch, at its Sacramento laboratory, under a continuing cooperative agreement with the Department of Water Resources.

STATE OF CALIFORNIA
THE RESOURCES AGENCY OF CALIFORNIA
DEPARTMENT OF WATER RESOURCES

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CHAPTER I. INTRODUCTION

Ground water basins are of vital importance to the economy of Alameda County. They are not only sources of readily available water but are major storage facilities. It is estimated that ground water basins supply water to more than 10,000 wells in the county. Although a considerable number of these wells are used only for the irrigation of lawns and gardens and are of shallow depth and small capacity, many industries and municipalities depend on ground water for their water supply. Further, irrigated agriculture depends almost entirely on ground water.

Numerous farm and home wells in Alameda County have been abandoned in recent years to make way for the phenomenal expansion of industrial and urban development. At the same time, new wells have been constructed to meet the increased demands for water.

Many of these new wells have not been constructed properly or have not been sealed adequately and thus may be allowing interchange of water between gravel layers. In the southwestern part of the county, adjacent to San Francisco Bay, water extraction in excess of normal recharge has depleted ground water supplies and water surface elevations have been drawn down below sea level. As a result, saline bay water has migrated into shallow gravel layers and degraded the fresh ground water occurring there. Degraded water from the shallow gravels then has moved vertically into deeper gravel layers that contained fresh ground water, in many instances through improperly constructed or inadequately sealed wells.

It is essential, therefore, that adequate standards for well construction and sealing be formulated and adopted in Alameda County to prevent impairment of the quality of ground water.

Authorization for Investigation

Authority for the formulation of water well construction and sealing standards is provided by Section 231 of the Water Code which states:

> 231. The department, either independently or in cooperation with any person or any county, state, federal or other agency, shall investigate and survey conditions of damage to quality of underground waters, which conditions are or may be caused by improperly constructed, abandoned or defective wells through the interconnection of strata or the introduction of surface waters into underground waters. The department shall report to the appropriate regional water pollution control board its recommendations for minimum standards of well construction in any particular locality in which it deems regulation necessary to protection of quality of underground water, and shall report to the Legislature from time to time, its recommendations for proper sealing of abandoned wells.

Strong local interest existed within Alameda County during the mid 1950's in the development of adequate well construction and sealing standards. A memorandum dated May 21, 1956, from the San Francisco Bay Regional Water Pollution Control Board, regarding increased salinity in certain portions of the lower aquifer in southern Alameda County, and our answer thereto recognized the need for a study of well construction practices in Alameda County and discussed the possibility of such an investigation. Subsequent meetings and correspondence with other agencies indicated a continuing interest in this problem and an awareness of the necessity for the formulation and enforcement of adequate well construction and sealing standards for the protection of ground water quality in Alameda County.

Beginning in July 1957, as a result of local concern regarding progressive deterioration of ground water supplies in Southern Alameda County and a subsequent Legislative directive (Item 263j of the Budget Act of 1957, California Statutes 1957, Chapter 600), the department conducted a detailed study of salt-water intrusion conditions in southern Alameda County. These studies resulted in Bulletin No. 81, titled "Intrusion of Salt Water Into Ground Water Basins of southern Alameda County." To make use of data collected in connection with the aforementioned investigation and to avoid duplication of effort, this investigation of well construction and sealing procedures for the entire Alameda County area was conducted concurrently with our salt-water intrusion study.

Area of Investigation

Alameda County lies adjacent to the east side of San Francisco Bay and extends eastward across the Diablo Range. It is bordered on the north by Contra Costa County, on the south by Santa Clara County, and on the east by San Joaquin County as shown on Plate 1, titled "Location of Area of Investigation."

The topography is dominated by northwest and southeast trending hills and ridges, ranging in elevation from sea level to 3,800 feet, and containing several intermontane valleys. Also prominant in the county is a large portion of the alluvial plain adjacent to San Francisco Bay. The northeastern corner of the county extends into the western flank of the San Joaquin Valley.

Principal ground water producing areas include: (1) Livermore Valley, located in the central part of the county; (2) Sunol Valley, located several miles south of Livermore Valley; (3) the alluvial plain (termed the "Bay Plain" in this report) which flanks the east side of San Francisco Bay; (4) Castro Valley, located immediately north of Hayward; and (5) the aforementioned portion of San Joaquin Valley.

Agriculture in Alameda County during its early years of settlement was limited mainly to dry farming. At the beginning of this century, however, the introduction of rural electrification and improvements in irrigation pumps brought about a transition from dry to irrigated farming. Expansion of irrigated areas has continued up to the present time.

In recent years, there also has been a tremendous development of industry and commerce in the San Francisco Bay area, expanding southward along the bay shore in Alameda County. Economic and population studies indicate that in the near future most of the Bay Plain will be utilized for industrial, commercial, or residential purposes and this expansion will overflow into Livermore Valley. As a result, agriculture will be relegated to a secondary role in the economy.

At the present time, the Bay Plain as far south as the City of Hayward and its suburbs is largely occupied by industry and urban development and is essentially a part of the east bay metropolitan area. Industry in this area is highly diversified. Among the more important manufacturing groups are those producing food and related products, textiles, and machinery. Part of the water supply for this metropolitan area is obtained from ground water. The East Bay Municipal Utility District, however, which is the principal water service agency for the area, obtains its water supply from local surface development and from the Mokelumne River in the Sierra Nevada via the Mokelumne Aqueduct. Although the district furnishes most of the water for municipal use, many industries maintain wells and there are numerous shallow domestic wells used for lawn and garden irrigation.

The City of Hayward owns and operates its own water supply system. Normally, approximately 15 percent of the city's water supply is pumped from wells; the balance is obtained from the San Francisco Water Department through the Hetch Hetchy Aqueduct.

South of Hayward, the economy is still basically agricultural, but industry and urban development is rapidly increasing. Major industries at the present time consist of salt production plants in the tideland near the bay, a sugar factory at Alvarado, a steel plant near Decoto, and a variety of smaller industries.

In contrast to the metropolitan area to the north, only a minor amount of imported water is utilized in the southern part of the Bay Plain. The major source of water for all uses is ground water. Limited quantities of water have been obtained from the Hetch Hetchy Aqueduct of the City of San Francisco and delivery of water from the Central Valley via the South Bay Aqueduct was initiated in June 1962. Alameda County Water District, which encompasses most of the southern part of the Bay Plain and extends northward to Hayward, is the principal water agency. The district furnishes water for municipal use, while industry and agriculture depend mainly on privately-owned wells for their supplies. Niles and Decoto are served by the Citizens Utilities Company, which obtains all of its supply from ground water.

Livermore Valley is predominantly a rural area, with an economy centered around agriculture. Industry is composed principally of wineries, several large sand and gravel plants near Pleasanton, and the University of California's radiation plant located just east of Livermore. The valley's water supply until recently has been obtained from ground water. Supplemental water deliveries from the South Bay Aqueduct were begun in June 1962. Several water service agencies furnish water for municipal use. Privately-owned wells are used for irrigation and rural domestic supplies.

Castro Valley is primarily a residential area. Its water supply is largely furnished by the East Bay Municipal Utility District. Use of ground water is restricted mainly to irrigation of lawns and gardens from small domestic wells.

Sunol Valley is primarily an agricultural area. Water for the community of Sunol and for lands owned by the City of San Francisco is furnished by the San Francisco Water Department from its Alameda Creek system. A few privately-owned wells give water for irrigation and domestic use.

In Vallecitos Valley, water for irrigation and domestic use is pumped entirely from ground water. However, the General

Electric Company's Vallecitos Atomic Laboratory, located near the west end of Vallecitos Valley, obtains its water from the San Francisco Water Department out of the Hetch Hetchy Aqueduct. Ground water development in La Costa Valley is limited and land is used primarily for cattle grazing.

Related Investigations and Reports

Publications utilized in the preparation of this report are listed in Appendix A. Reference is made to these publications in the text by means of numbers in parentheses, e.g. (1). Of particular importance are the following bulletins prepared by the Department of Water Resources:

Bulletin No. 13, "Alameda County Investigation" (9), containing detailed information on the water resources of the county south of the San Leandro Creek Watershed.

Bulletin No. 74, "Recommended Minimum Well Construction and Sealing Standards for the Protection of Ground Water Quality, State of California" (14), presenting general information concerning water well construction methods and materials.

Bulletin No. 81, "Intrusion of Salt Water Into Ground Water Basins of Southern Alameda County"(13), presenting detailed information concerning the nature and extent of salt-water intrusion into gravel layers containing fresh water in southern Alameda County, and an analysis of the effect of poorly constructed or improperly sealed wells upon this salt-water intrusion.

Scope of Investigation and Report

The investigation leading to this report consisted of a review and evaluation of existing data on the occurrence and nature of ground water in Alameda County with special reference toward those conditions that directly influence construction and sealing of water wells. Previously compiled data were supplemented by information obtained in the field during 1958-59. Field work included the following:

(1) A survey of the ground water basins to determine factors influencing the occurrence and movement of ground water.

(2) Interviews with water agencies and well drillers to obtain information on well construction methods and materials.

(3) A survey of active and abandoned wells to determine physical conditions and prevalent construction and sealing practices.

(4) Collection of water samples for mineral analyses to determine the general quality of ground water and to define water quality problem areas.

Geologic, hydrologic, and water quality conditions existing in each ground water basin are among the principal factors to be considered when water well construction and sealing standards are formulated. Accordingly, information on the occurrence and nature of ground water in Alameda County is included in this report. Specific water quality problem areas are pointed out, and prevalent methods and materials used in constructing and sealing wells are discussed. Recommendations for standards of water well construction and sealing considered necessary for the protection of ground water in Alameda County, are presented.

CHAPTER II. OCCURRENCE AND NATURE OF GROUND WATER

There are five principal ground water producing areas in Alameda County. The two largest and most important of these areas, with respect to ground water production, are the Bay Plain portion of the Santa Clara Valley ground water basin which encompasses an area of approximately 189 square miles and Livermore Valley ground water basin, which has an areal extent of approximately 94 square miles. The other principal water producing areas are Sunol and Castro Valley ground water basins and a portion of the San Joaquin Valley Basin. All of these ground water producing areas, with the exception of Castro Valley, are subdivided into subbasins or subareas. Faults or other geologic structures or conditions that impede ground water movement were utilized as a basis for the subdivisions. The ground water basins and subdivisions are listed in Table 1 and their areal extent is shown on Plate 2, titled "Ground Water Producing Areas in Alameda County, Showing Geologic Conditions."

Many of the small creeks in the mountainous areas of Alameda County are flanked by water-bearing deposits. These areas are considered to be too small in areal extent to be classified as ground water basins, however, they produce ground water in limited quantities. Accordingly, the small valley fill areas have received minor consideration during the course of this investigation.

TABLE 1

PRINCIPAL GROUND WATER PRODUCING AREAS AND SUBDIVISIONS
ALAMEDA COUNTY

Basin Number*	Name	Symbol (Plate 2)
2-8	Castro Valley Ground Water Basin	
2-9	Santa Clara Valley Ground Water Basin (Bay Plain)	
	Subareas	
	San Leandro Cone Confined Ground Water Area	A
	San Lorenzo Cone Confined Ground Water Area	B
	Niles Cone Confined Ground Water Area	C
	Niles Cone Forebay Area, Newark Aquifer	D
	Stivers Alluvial Area	E
	Warm Springs Alluvial Plain	F
	Mission Upland	G
	Berkeley Alluvial Plain	H
	Oakland Upland	I
	Merritt Sand	J
2-10	Livermore Valley Ground Water Basin	
	Subbasins	
	Livermore Subbasin	1
	Parks Subbasin	2
	Santa Rita Subbasin	3
	San Ramon Subbasin	4
	Pleasanton Subbasin	5
	Livermore Upland	6

TABLE 1 (Continued)

Basin Number*	Name	Symbol (Plate 2)
2-11	Sunol Valley Ground Water Basin	
	Subbasins	
	Sunol Subbasin	1
	Vallecitos Subbasin	2
	La Costa Subbasin	3
	Sunol Upland	4
5-22	San Joaquin Valley Ground Water Basin	
	Subareas	
	San Joaquin Valley	A
	West Side Upland	B

* California State Department of Public Works, Division of Water Resources. "Ground Water Basins in California." November 1952

Geology of Ground Water Producing Areas

For this report, the geologic investigation of Alameda County was limited to a study of those geologic features that affect the occurrence, nature, and movement of ground water in the water-bearing deposits, with special reference toward geologic conditions that directly influence water well construction and sealing. The location, extent, physical characteristics, structure, and continuity of Quaternary and Plio-Pleistocene sediments, which are the principal water-bearing deposits in Alameda County, are discussed.

Geologic formations in the county include igneous, metamorphic, and sedimentary rock types which range in age from pre-Cretaceous to Recent. In relation to the occurrence of ground water, these geologic formations can be separated into two groups. The first group includes the water-bearing deposits which are of major importance as a source of ground water in the county. The second group includes consolidated rocks that are of very little importance as a source of fresh ground water and so are considered to be essentially nonwater-bearing. The areal extent of water-bearing and nonwater-bearing groups is shown on Plate 2.

Ground water in Alameda County occurs primarily in unconsolidated alluvial deposits of late Quaternary age and in older semiconsolidated deposits of Tertiary-Quaternary age. The most important reservoir of readily available ground water at the present time is the unconsolidated late Quaternary alluvium in the Bay Plain and in Livermore Valley ground water basin. An important secondary reservoir in these basins is the semiconsolidated

Tertiary-Quaternary sediments that occur adjacent to the alluvium and underlie it at depth. At present, only minor quantities of ground water are produced from any of the water-bearing deposits in Sunol Valley and Castro ground water basins and from the small portion of the San Joaquin Valley included in Alameda County.

Nonwater-bearing geologic units consist of consolidated rocks, most of which are pre-Tertiary in age, although some are Tertiary. These rocks are considered to be essentially nonwater-bearing as they do not absorb, transmit, or yield water readily to wells and often contain water of poor quality. However, in areas where these rocks are highly jointed or fractured, they may yield sufficient quantities of fresh ground water to wells to satisfy limited needs. The nonwater-bearing rocks, which have been severely folded and faulted, are exposed in the hills adjacent to the water-bearing sediments and underlie them at depth.

Folding and faulting have formed the predominant geologic structural features in Alameda County and strongly influence the occurrence and movement of ground water in the larger ground water basins. Structural control dominates all of the intermontane valleys except possible Castro Valley. The Bay Plain is part of the large Santa Clara Valley ground water basin which has been developed in a depressed area resulting principally by downward movement along faults located on the edge of the basin. Livermore Valley has been developed in an east-west trending faulted syncline resulting from folding. Sunol Valley probably has been developed as a result of movement along the Calaveras fault and another closely adjacent fault. San Joaquin Valley, in which the northeastern corner of the county lies, has been developed in a great structural trough.

Ground water occurs in both confined and unconfined aquifers in the water-bearing deposits underlying the Bay Plain and the Livermore Valley ground water basin. Confined aquifers, as used in this bulletin, refer to strata of water-bearing material that are overlain by material sufficiently impervious to sever free hydraulic connection with overlying ground water bodies or the ground surface. Ground water in a confined aquifer may or may not be under pressure depending on whether or not its static water level is above or below the bottom of the overlying impervious stratum. An unconfined aquifer refers to a stratum of water-bearing material that is not overlain by impervious materials. It contains water that is not under pressure. An unconfined aquifer may be underlain by aquifers that are confined.

The areal extent of confined and unconfined aquifers in Alameda County is shown on Plate 3, titled "Ground Water Conditions and Lines of Equal Elevation of Ground Water in Bay Plain, Spring 1958" and Plate 4, titled "Ground Water Conditions and Lines of Equal Elevation of Ground Water, Spring 1961." Thick, extensive blue clay layers of marine and tideland origin confine ground water under pressure in several fairly well-defined sand and gravel aquifers beneath the Bay Plain as shown on Plate 5, titled "Geologic Sections." In Livermore Valley, the confining clays are of lacustrine origin (deposited in lakes). Ground water in the remainder of the ground water basins of Alameda County occurs essentially in unconfined aquifers.

Recharge to unconfined aquifers in Alameda County is accomplished primarily by direct infiltration of precipitation, stream flow, and return irrigation water, as well as by artificial recharge from spreading ponds and injection wells. Confined ground water aquifers are recharged mainly by underflow from adjacent ground water bodies.

A more detailed discussion of the occurrence and nature of ground water in each ground water peoducing area is included in the latter part of this chapter.

Quality of Ground Water in Ground Water Producing Areas

During the course of this investigation, a survey was made of the mineral quality of the ground water in Alameda County. These data, in conjunction with historical water quality data, were used to evaluate general water quality and delinate specific water quality problems areas within the ground water basins of the county. Criteria for evaluating quality of water relative to existing or anticipated beneficial uses are presented in Appendix B, titled "Water Quality Criteria."

Data used in evaluating the mineral quality of ground water included standard mineral analyses and partial mineral analyses. Also available were standard mineral analyses and numerous field laboratory analyses for chloride concentrations and electrical conductivity made of ground water in the southern part of the Bay Plain during the study of salt-water intrusion [13].

Results showed that ground water of Alameda County is generally of satisfactory mineral quality for most beneficial uses. However, portions of the basins, as shown on Plate 6, titled

"Water Quality Conditions," contain water that is of poor quality and unsuitable or undesirable for certain uses. The major problem area of this nature is located in the southern part of the Bay Plain where sea water has invaded an extensive area of the ground water basin. Water quality problem areas in Livermore Valley are of lesser extent and are associated principally with excessive boron concentrations in wells located in the northern and eastern part of the valley. Small and more localized areas of poor quality water also are found in parts of the county's other ground water basins. The mineral quality of water in each ground water basin is discussed in more detail in the latter part of this chapter.

In this discussion nitrates are evaluated in accordance with a limiting concentration of 10 parts per million (ppm) nitrogen (44 ppm nitrates) recommended for drinking water by the California Department of Public Health. It should be noted that high nitrate concentrations are undesirable because of their relationship to infant methemoglobinemia (blue babies). They also have considerable significance as indications of possible pollution, since a common source of nitrate is organic wastes emanating from fertilizers, cesspools, and surface drainage.

Water containing high chloride concentrations generally is evaluated with respect to its suitability for irrigation, since chloride concentrations in excess of 350 ppm are regarded as probably harmful to most crops and unsatisfactory for all but the most tolerant (Appendix B). Concentrations in excess of 250 ppm are considered undesirable for drinking water.

Occurrence and Nature of Ground Water in Individual Ground Water Basins or Ground Water Producing Areas

As previously mentioned, the Bay Plain and the Livermore Valley ground water basin are the principal ground water producing areas of Alameda County. Therefore, these areas were studied in detail to evaluate problems and water well construction and sealing practices.

Bay Plain

The Bay Plain is a part of the large Santa Clara Valley ground water basin [8]. The Bay Plain of Alameda County is situated between San Francisco Bay on the west and the Diablo Range on the east and extends from the Contra Costa County boundary on the north to the Santa Clara County boundary on the south. It includes an area of approximately 189 square miles,

Occurrence of Ground Water. Water-bearing formations in the Bay Plain include unconsolidated predominately alluvial deposits of late Quaternary age and older semiconsolidated sediments principally of Tertiary-Quaternary age. Late Quaternary alluvium is exposed on the surface throughout most of the Bay Plain (Plate 2). Tertiary-Quaternary deposits are exposed at the surface several miles southeast of Irvington and east of Lake Merritt and probably underlie the late Quaternary alluvium. The Tertiary-Quaternary sediments and overlying late Quaternary alluvium are so similar in lithology that it generally is not possible to differentiate between them in the logs of wells.

The water-bearing deposits consist of layers and lenses of sand and gravel separated by thick layers of silt and clay.

In the fairly recent geologic past, the Bay Plain probably has been subjected to several periods of marine inundation. As a result, materials similar to the fine-grained silts and clays now present on the bottom on San Francisco Bay were deposited over permeable alluvial fan materials [13]. This resulted in interlayering of the extensive, relatively impermeable bay clays and the permeable alluvial sands and gravels, and the formation of confined aquifers beneath the greater part of the Bay Plain. Geologic sections on Plate 5, show the relationship of water producing sand and gravel layers and confining clays.

The principal barriers to the lateral movement of ground water in the Bay Plain are the Hayward fault and the Coyote Hills (Plate 4). The Hayward fault is a pronounced structural feature. It lies along the base of the hills from north of San Leandro to Niles, extends across late Quaternary alluvial deposits to Irvington, and separates the older semi-consolidated Tertiary-Quaternary deposits from the younger late Quaternary alluvium in the Mission San Jose-Warm Springs area. It is a well recognized ground water barrier and has many surface expressions. The Coyote Hills, an elongated low range of hills near Newark, is composed of consolidated nonwater-bearing rocks. At depth, these rocks form a barrier to the movement of ground water; however, the full extent of the buried portion of these hills and its influence on the movement of ground water is unknown. Another fault, the Mission fault, east of Niles, is not considered to be a barrier to the lateral movement of ground water. However, it is probably allowing poor quality water, that originates at depth, to move upward into the ground water basin and influence the quality of ground water in the immediate area. This is evidenced by high boron concentrations found in ground water in this area.

The Bay Plain of Alameda County has been subdivided into ten subareas, the presence of faults or other geologic structures or conditions that impede ground water movement being the basis for the subdivision. The subareas are listed in Table 1, and Plate 2 shows their location and areal extent.

The larger and more important of the subareas, with respect to water well construction, are those underlain by confined aquifers in the San Leandro, San Lorenzo, and Niles alluvial cones. The forebay area for the Newark aquifer of the Niles Cone, Stivers alluviated area, Warm Springs alluvial plain, Mission upland, Berkeley alluvial plain, outcrop area of the Merritt sand, and the Oakland upland form the remainder of the ground water basin subareas.

Ground water occurs in both confined and unconfined aquifers in the Bay Plain (Plate 3). Relatively continuous layers of marine clay confine aquifers in the San Leandro, San Lorenzo, and Niles alluvial cones and the Warm Springs and Berkeley alluvial plains. In the Mission and Oakland uplands, aquifers probably are essentially confined; however, there are not enough subsurface data to define and correlate the confining members. Unconfined aquifers occur in the Merritt sand, the Stivers alluvial area and in the forebay area for the Newark aquifer.

To a depth of approximately 400 feet, the confined ground water subareas of the Niles, San Leandro, and San Lorenzo alluvial cones and the Berkeley and Warm Springs alluvial plains are considered to be separate hydraulic units [8]. The aquifers occurring within this depth interval probably do not extend across subarea boundaries. There are three aquifers occurring above 400 feet in depth in the confined ground water area of the Niles Cone. They are thick and relatively continuous and are separated from one another and confined by continuous blue clay layers (Plate 5, titled "Geologic Sections"). The Newark aquifer, capped by a clay layer approximately 40 feet in thickness, extends to a maximum depth of approximately 175 feet (Plate 5); the Centerville aquifer occurs between 190 and 200 feet; and the Fremont aquifer is between approximately 250 and 300 feet in depth. All of these aquifers and their confining clay layers extend westward beneath San Francisco Bay. Aquifers that probably are equivalent to those in the Niles Cone occur beneath the surface of the San Leandro and San Lorenzo cones but are much thinner and less extensive. The Berkeley and Warm Springs alluvial plains contain thin water-bearing layers of sand and gravel interspersed with thick sections of sandy clay and clay.

There are three more confined aquifers found below a depth of 400 feet in the confined ground water area of the Niles Cone. They appear to be distinctly separate hydraulic units sandwiched between clay aquicludes. These aquifers probably are relatively continuous throughout the Bay Plain.

There are at least three areas in which minor aquifers of limited areal extent overlie clay layers confining upper aquifers. Their areal extent is not definitely known. One of them is located in the Niles Cone and extends from Centerville almost to Newark (Plate 5). This aquifer also is confined by clay with the exception of a relatively small forebay area. It produces limited quantities of water to wells. The other two aquifers are not confined. One is located in the Valle Vista area and the other near Alameda (Plate 3).

Lines of equal elevation of ground water in wells in the Bay Plain during the springs of 1958 and 1961 are presented on Plates 3 and 4, respectively. In the northern and central part of this area, the water surface in upper aquifers had a bayward gradient except for small localized areas where landward gradients were established due to pumping depressions. In the Niles Cone to the south, a trough-like depression existed in the water surface of the Newark aquifer. The depression was generally semicircular in shape, extending through Centerville and curving northeastward and eastward from there. A bayward pressure gradient existed on the Niles side of this trough and a landward gradient on the bayward side.

In the Bay Plain north of the Niles Cone, lines of equal elevation of the water surface in deeper aquifers were drawn to represent a composite water surface from undifferentiated aquifers underlying upper aquifers. In the confined ground water of the Niles Cone, however, the lower aquifer lines of equal elevation represent the water surface in the Centerville aquifer only.

In the ground water subareas north of Hayward, water levels in wells perforated in upper aquifers were generally within 5 to 30 feet of ground surface in the spring of 1958. In contrast, the water levels in wells in the upper (Newark) aquifer of the Niles Cone were generally from 5 to 90 feet below the ground surface.

Water level data obtained in the springs of 1958 and 1961 indicate that the water surface in lower aquifers north of Hayward sloped generally in a bayward direction. Elevation of the water surface in 1958 ranged from above sea level to more than 50 feet below sea level (Plate 3). In 1961, the elevation of the water surface ranged from 30 feet above to 80 feet below sea level (Plate 4). In the Niles Cone, the water surface contours of the Centerville aquifer, which underlies the Newark aquifer, varied from about 26 to 40 feet below sea level in 1958 and from 40 to 60 feet below sea level in 1961. Ground water movement in deeper aquifers of the Niles Cone in springs of 1958 and 1961 was toward the bay from the general vicinity of the forebay area for the Newark aquifer. It is possible that this forebay also is a recharge area for the deeper aquifers.

In Stivers alluvial area east of the Hayward fault, ground water moved in a bayward direction in the spring of 1958. Water levels in this ground water subarea were approximately 60 feet higher than the water levels in the Niles Cone forebay area immediately west of the fault (Plate 3).

Unconfined aquifers in the Bay Plain are recharged by the deep infiltration of stream flow, precipitation, irrigation water, and water from spreading ponds. Confined aquifers are replenished principally by the lateral movement of ground water from adjacent ground water bodies, with which they are in hydraulic continuity.

Water Quality. Mineral analyses indicate that ground water in the Bay Plain is generally of good mineral quality and suitable for most beneficial uses. Areas in which water quality problems are known to occur are discussed in the next several paragraphs.

Nitrate concentrations in excess of 44 ppm, the upper recommended limit for drinking water (Appendix B), are frequently found in wells throughout the Bay Plain. Locations of some of these wells for which mineral analyses are available are shown on Plate 6. Maximum nitrate concentration of 190 ppm was found in a well 72 feet deep in the vicinity of Hayward.

Water quality problems due to salt-water intrusion in the Bay Plain are confined to that portion of the ground water basin located south of San Leandro. This area of salt-water intrusion is shown on Plate 6. Over a period of approximately 30 years, the Newark aquifer south of Alvarado and portions of other shallow aquifers as far north as San Leandro have been invaded by sea water. East of Coyote Hills, however, there is an area which has not been degraded, the hills probably having served as a barrier to movement of salt water. Saline water probably intruded the Newark aquifer through natural and man-made openings in the confining layer of bay muds and clays. It appears that the most probable point of entry with respect to direct movement of saline bay water into the Newark aquifer is beneath the deepest part of the narrow channel under Dumbarton Bridge. Erosion by tidal action probably has stripped off the clay layer and exposed the underlying gravels [8].

As a result of degradation in the Newark aquifer, a major portion of the pumping activity has been transferred to the deeper aquifers. In the last few years, over 8,000 acres of the Centerville aquifer, which occurs at a depth of approximately 200 feet, also have been invaded by salt water in the general vicinity of Centerville and Newark, as shown on Plate 6. In the vicinity of Alvarado, aquifers below the Centerville aquifer have been degraded, although the Centerville aquifer contains water of satisfactory quality in this area.

Results of the study of salt-water intrusion indicate that in general saline water in the lower aquifers has migrated downward from the degraded Newark aquifer. Passage of saline water into the lower aquifers is considered to have taken place through improperly constructed or inadequately sealed wells, directly through more permeable portions of the confining strata separating the aquifers, and/or through discontinuities in these strata. During the investigation, 100 possible problem wells were tested. Twenty of these wells were found to be allowing interchange of saline water between aquifers. Sixteen of these defective wells were sealed or repaired under supervision of the Department of Water Resources. Information concerning the remaining four wells and three other possible problem wells which could not be tested during the investigation due to lack of permission by the owners were referred to the San Francisco Bay Regional Water Pollution Control Board. Subsequently, all of these wells have been sealed, five of them under the direction of the regional board.

North of San Leandro, several wells were found to contain saline water. Mineral analyses (made during the years 1957 and

1958) for 114 wells in this vicinity showed chloride concentrations of 100 ppm or more in 31 wells, 3 of which contained more than 350 ppm chlorides. Locations of wells containing more than 350 ppm chlorides are shown on Plate 6. These wells are all more or less isolated and have probably resulted from fingers of salt-water intrusion, but there is no indication that intrusion has occurred on an areal basis, such as in the southern part of the Bay Plain.

Perched ground water of poor quality exists in a limited area northwest of Decoto (Plate 4). Analyses of water from test holes indicate the concentration of mineral constituents in the perched water fluctuates widely. Total dissolved solids range from 674 to 4,060 ppm, chlorides from 14 to 1,000 ppm, nitrates from 1.3 to 58 ppm, boron from 0.07 to 5.6 ppm, and sodium from 32 to 91 percent of base constituents.

Boron concentrations of 0.5 ppm or greater commonly occur in the ground water in an area immediately south of Niles (Plate 6). The maximum boron concentration found in ground water from this area during 1957 and 1958 was 1.5 ppm, however; higher concentrations have been found in the past analyses. Studies indicate that the source of boron is probably near the Mission fault, which lies immediately to the east of the area. Water emanating from the fault zone is characterized by a relatively high bicarbonate concentration in addition to boron.

Livermore Valley Ground Water Basin

Livermore Valley ground water basin includes a large intermontane valley-floor area and hilly uplands. It encompasses an area of approximately 94 square miles. In the upland area south of Pleasanton, the Livermore Valley ground water basin is separated from the Sunol Valley ground water basin principally along a topographic divide (Plate 2).

Occurrence of Ground Water. Water-bearing formations in the Livermore Valley basin include unconsolidated alluvial deposits of late Quaternary age and older semiconsolidated sediments of Tertiary-Quaternary age. Late Quaternary alluvium occurs in the relatively flat valley-floor area and has a maximum thickness of over 350 feet in the western part of the valley, northwest of Pleasanton. Its thickness is less to the north toward Dublin and easterly from the Pleasanton fault. The older Tertiary-Quaternar water-bearing deposits are exposed at the surface in the hilly uplands immediately south and west of the valley-floor and in several small hills near Livermore (Plate 2). These semiconsolidated sediments are reported to reach a thickness of approximately 4,000 feet [9]. They dip gently toward Livermore Valley from the uplands to the south and probably underlie the late Quaternary alluvium at depth. The Tertiary-Quaternary sediments and the overlying late Quaternary alluvium are so similar lithologically that it is extremely difficult to differentiate between them in the logs of water wells. The older Tertiary-Quaternary deposits generally are compacted and cemented more than the younger alluvium a contain a greater portion of sandy silt and clay.

The water-bearing deposits consist of layers and lenses of sand and gravel separated by discontinuous layers of silt and clay. In the fairly recent geologic past, periodic faulting in the area southwest of Pleasanton probably created a barrier across what is now Arroyo de la Laguna and lakes occupied the western one-third of Livermore Valley. Fine-grained silts and clays were laid down on the lake bottoms over previously deposited permeable alluvial materials forming a succession of permeable sand and gravel layers and relatively impermeable lake beds (Geologic Sections, Plate 5). Flowing wells were common in this area at one time, but now they have ceased to flow.

The principal barriers to lateral movement of ground water in Livermore Valley ground water basin are the Livermore, Pleasanton, and Parks faults (Plate 3). The Livermore and Pleasanton faults are roughly parallel and trend northwesterly. The Parks fault trends in an east-west direction in the northern part of the valley but west of the Pleasanton fault its trend changes gradually to a northeast-southwest direction. Geologic, water level, and water quality data indicate that these faults are barriers to ground water movement. The small hills located in the valley-floor north of Livermore also are barriers to the movement of ground water at depth. Although their barrier effect is very localized, their presence in the valley suggests that some structural feature may occur and extend further east below the ground surface to form a more complete barrier across the northeastern part of Livermore Valley.

Livermore Valley ground water basin has been subdivided into six subbasins [9], based on faults or other geologic structures or conditions that restrict the lateral movement of ground water. The subbasins are listed in Table 1 and shown on Plate 2. The Santa Rita and Pleasanton subbasins are probably the most important with respect to ground water supply and storage. Late Quaternary alluvium, which is the most prolific water producing formation in the basin, probably attains its maximum thickness and permeability in these areas. Livermore and San Ramon subbasins and the Livermore upland form the remainder of the subbasins in the Livermore Valley ground water basin.

Ground water occurs in both confined and unconfined aquifers in this basin. Unconfined aquifers occur in Quaternary alluvial deposits in the Livermore subbasin and in the southern part of the Santa Rita subbasin (Plate 3). The aquifers underlying the remainder of the valley floor are confined by a series of blue lake-bed clays and silty clays up to 100 feet in thickness, the upper beds being only a few feet below ground surface (Geologic Sections, Plate 5). Water-bearing gravel and sandy gravel layers from 10 to 100 feet in thickness underlie and are separated by confining clay layers.

Water in the semiconsolidated Tertiary-Quaternary deposits underlying late Quaternary alluvium in the valley-floor area of Livermore Valley ground water basin probably occurs largely in confined aquifers, and deep wells in the eastern portion of the valley generally obtain water supplies from these aquifers. In the upland south of Livermore Valley, where these older deposits are exposed on the surface, ground water probably occurs in unconfined aquifers. However, as it moves northward down the prevailing dip of the permeable sediments, the water probably moves beneath impermeable layers and becomes confined within a relatively short distance.

Lines of equal elevation of the water surface in wells in Livermore Valley ground water basin in spring of 1961 are presented on Plate 4. Ground water at that time was moving toward the west end of the valley, in the general direction of the surface slope. The lines show the marked barrier effect of the Livermore, Pleasanton, and Parks faults. In fall of 1959, water levels in deep wells were approximately 100 feet higher on the eastern side of Livermore fault than those on the western side. The water level differential was 50 feet across the Pleasanton fault, with the eastern side also having the higher level. Due to water level differential, ground water could move only westward across or through these barriers into adjacent ground water subbasins. Water level data indicate that the Parks fault is also a ground water barrier. In May 1961, a water level differential of approximately 20 feet existed across this fault, with the northern side having the higher levels. A ground water depression, evidently caused by pumping concentrations, was located in the Pleasanton subbasin (Plate 4).

Although ground water movement throughout Livermore Valley ultimately is toward the west end of the valley into the Pleasanton subbasin, subsurface outflow from the principal aquifers evidently does not occur at present, since the ground water gradient southwest of Pleasanton is northward toward the pumping depression.

Recharge to unconfined aquifers underlying the Livermore Valley ground water basin is accomplished by deep infiltration of stream flow, precipitation, and return irrigation water into permeable sediments. In the unconfined aquifers of the Quaternary alluvium of the valley, infiltrating water probably can move directly downward to the water table and then laterally under the influence of the existing hydraulic gradient. Water that has infiltrated permeable layers of the older Tertiary-Quaternary sediments in the upland area probably moves down the dip of the sediments, beneath late Quaternary alluvium in the valley, and then possibly, in places, upward into the overlying alluvium. Confined aquifers in the Pleasanton subbasin are essentially recharged by lateral movement of water from the adjacent subbasins to the north and east, across or through the barrier faults.

Water Quality. The mineral quality of ground water in the Livermore Valley ground water basin is dependent largely upon the quality of the source of replenishment. Ground water in the central, southern, and western parts of the basin, the major part of the valley's water supply, is a magnesium or calcium-magnesium bicarbonate type, reflecting the mineral characteristics of water of Arroyo Mocho and Arroyo del Valle (Plate 6). Ground water in this area, with the exceptions noted below, is of good mineral quality. Total dissolved solids range from 302 to 814 ppm, and concentrations of mineral constituents, except for nitrate and boron, are generally within acceptable limits for most beneficial uses.

Nitrate concentrations is excess of 44 ppm have been found in water from wells located principally in the vicinity of the town of Livermore and in a few isolated wells throughout the ground water basin (Plate 6). The maximum nitrate concentration found in the ground water during 1957 was 106 ppm in a well immediately west of Livermore.

Boron in excess of 0.5 ppm has been found in wells in a small localized area directly south of the town of Livermore

(Plate 6). In contrast to the surrounding ground water, which is a magnesium bicarbonate type, the water in this area is a sodium bicarbonate type.

Ground water in Livermore Valley east of the town of Livermore and north of Arroyo Las Positas is generally of a sodium type water which frequently is high in concentrations of total dissolved solids, chlorides, and boron. Maximum mineral concentrations have been measured in samples from wells in the extreme northeast part of the ground water basin, where as much as 4,814 ppm total dissolved solids, 2,288 ppm chlorides, 70 ppm boron, and 91 percent sodium were found during 1957 and 1958. Plate 6 shows the location of wells in which chloride concentrations exceeded 350 ppm, the recommended maximum for Class 2 irrigation water. The sodium chloride type water which occurs in this area reflects the mineral quality of water entering Livermore Valley from the hills to the north and east of the ground water basin. Although streams from this part of the valley contribute but a small percentage of the total recharge to the ground water basin, they commonly contain excessive quantities of dissolved solids. Water from tributaries to Arroyo Las Positas from the northeast have contained as high as 6,240 ppm total dissolved solids, 1,900 ppm chlorides, 26.9 ppm boron, and 82 percent sodium. These high concentrations occur only at times of very low flow, however. Of particular importance as a source of degrading waters are the older consolidated rocks of marine origin which underlie the water-bearing sediments at a relatively shallow depth in this area and are exposed approximately three miles northeast of Livermore (Plate 2). Water from a spring flowing from these rocks was found to contain a boron concentration of 53 ppm and chlorides of 902 ppm.

The principal water quality problem in Livermore Valley ground water basin is the presence of relatively high concentrations of boron in the eastern part of the valley which, in many instances, limit the use of the ground water for irrigation. Plate 6 shows the general areas in which wells sampled during the investigation contained abnormal quantities of boron during 1957 and 1958. Boron is closely associated in the ground water basin with a sodium bicarbonate or sodium chloride type of water. Out of 41 wells in which ground water was found to contain boron in excess of 1.0 ppm, all but two had sodium as the predominant cation.

Excessive concentrations of boron in water from the northeastern part of the ground water basin are attributed largely to streams which drain saline water-bearing marine formations exposed upon the surface in the hills to the northeast. In addition, information from oil wells and deep water wells drilled in Livermore Valley area indicates that water-bearing deposits of the valley are underlain at depth by saline water that originally was entrapped in the underlying marine sediments. This water contains relatively high concentrations of boron and is under considerable artesian pressure. It probably can migrate upward through deep wells that are improperly constructed or inadequately sealed or along faults, shear zones, or other natural avenues of escape into the overlying fresh ground water reservoir. This may explain why the boron content of ground water appears to increase with depth beneath Livermore Valley.

TABLE 2

MINERAL ANALYSES OF WATER FROM SPRINGS
AND ABANDONED OIL WELLS
LIVERMORE VALLEY
Constituents in ppm

Source and location	Depth	Date drilled	Date sampled	Ca	Mg	Na	K	CO_3	HCO_3	SO_4	Cl	B	Total dis-solved solids
Spring No. 1 (T2S/R2W-26F)	---	---	9/30/58	50	41	770	8.2	---	493	99	902	53	2170
Spring No. 2 (T3S/R3W-15Q)	---	---	10/1/58	124	18	154	2.2	---	397	58	236	3.9	824
Well No. 1 (T2S/R2W-26F)	1100	Before 1900	9/30/58	31	0.4	606	5.8	---	422	0.5	738	30	1640
Well No. 2 (T3S/R3E-15Q)	3154	1911 1921	10/1/58	22	12	348	3.5	---	602	9.5	243	54	1010
Well No. 3 (T3S/R3E-21A)	1560	1928	10/1/58	6.4	2.4	1090	2.4	174	1420	0.0	690	50	2730
Well No. 4 (T3S/R3E-16R)	1025	1926	10/1/58	43	62	207	10	12	282	302	189	1.2	996

Historical records show 18 oil wells were drilled in Livermore Valley area prior to 1936. Since that year, oil wells have been sealed under the direction of the State Division of Oil and Gas, but prior to that time many were left unsealed. Six abandoned oil wells were located during 1957 and 1958. Slightly saline water was flowing from four of these wells during this time; although flows were very small, less than one gallon per minute. The other two wells were filled with debris. Locations of the six wells are shown on Plate 6. Mineral analyses of water produced by the four flowing oil wells and two springs nearby are contained in Table 2.

A record of mineral analyses made at intervals during the drilling of a well southeast of Livermore showed that boron conten of the water increased from 0.7 ppm near the surface to 7.5 ppm at 463 feet. Water from a well adjacent to this deeper well contained 0.3 ppm boron near the surface, increasing to 2.6 ppm at a depth of 307 feet. Both of these wells were flowing and although they had been abandoned and filled in, water was seeping from the deep well when it was inspected in September 1958.

Sunol Valley Ground Water Basin

Sunol Valley ground water basin is situated immediately south of Livermore Valley ground water basin. It encompasses an area of approximately 28 square miles and includes three small relatively flat valley-floor areas and a hilly upland (Plate 2 and Table 1).

Occurrence of Ground Water. Water-bearing formations are similar to those occurring in the Livermore Valley basin.

They include unconsolidated alluvial deposits of late Quaternary age that occur in the valley-floor areas and Tertiary-Quaternary sediments which probably underlie the younger deposits and are exposed in the upland. The older semiconsolidated Tertiary-Quaternary deposits probably underlie the alluvium of the valley-floor. The water-bearing sediments consist of discontinuous layers and lenses of sand and gravel separated by and interspersed with discontinuous layers of silt and clay. The alluvium is highly permeable, but limited data indicate that it is very thin, and water wells generally penetrate the underlying Tertiary-Quaternary sediments also and produce water from both water-bearing units. The alluvium probably reaches a maximum thickness of about 160 feet in Sunol Valley. Actual thickness of the Tertiary-Quaternary deposits in this ground water basin is not known.

Several faults occur in the Sunol Valley ground water basin, but there are not sufficient geologic or hydrologic data to ascertain whether or not they are barriers to the movement of ground water.

This basin has been subdivided into four subbasins: the Sunol, Vallecitos, La Costa, and Sunol upland subbasins [9]. Table 1 lists the subbasins and Plate 2 shows their location and areal extent.

Ground water probably occurs in unconfined aquifers in the late Quaternary alluvium of the valleys and in portions of the upland area where permeable beds of the older Tertiary-Quaternary sediments are exposed at the surface. Water in these older deposits, that underlie the alluvium of the valleys, probably occurs to a large extent in confined aquifers, although the areal extent of the confining beds is not known definitely.

Very limited water level data are available due to the small number of wells in this ground water basin. Ground water probably moves in the general direction of the topographic slope in the valleys. The Sunol filter galleries, owned by the City of San Francisco, probably influence ground water movement in the Sunol subbasin. In the Sunol upland, the topographic slope probably generally governs the water movement; however, the prevailing northeastward dip of the permeable beds also may exert an influence on movement of ground water.

Water Quality. Mineral analyses of water from wells in the Sunol Valley ground water basin indicate that the quality of ground water produced from alluvium in the valley-floor areas is generally within acceptable limits for irrigation water. Some of the shallow wells, however, produce water having a nitrate concentration greater than 44 ppm which may indicate pollution from a surface source. Analyses also indicate that the Tertiary-Quaternary sediments contain water of poorer quality than that in the younger alluvium. For instance, wells in the vicinity of Vallecitos Valley, producing ground water from these older sediments, have excessive concentrations of boron and chloride.

Castro Valley Ground Water Basin

Castro Valley ground water basin is a thinly alluviated structural basin located directly north of Hayward. It encompasses an area of approximately three and one-half square miles.

The basin is of minor importance as a source of ground water, although there is some domestic production for irrigation of lawns or gardens.

Occurrence of Ground Water. Water-bearing deposits in Castro Valley consist of late Quaternary alluvium. These deposits are only 40 to 80 feet thick in the valley and overlie nonwater-bearing rocks.

Ground water in Castro Valley probably occurs in unconfined aquifers and can be recharged by the infiltration and vertical movement of water from the ground surface. The probable sources of recharge are stream flow, precipitation, and possibly some return irrigation water. Movement of ground water in Castro Valley is probably in a general southwest direction into the Bay Plain area.

Water Quality. Information regarding the quality of ground water is very limited. The few mineral analyses available from wells indicate that the ground water is of satisfactory quality except for boron locally. A boron concentration of 2.3 ppm has been found in one well.

San Joaquin Valley Ground Water Basin

The northeast corner of Alameda County includes several square miles of the western side of the San Joaquin Valley, the largest ground water basin in California.

Occurrence of Ground Water. Water-bearing formations in this portion of Alameda County include late Quaternary alluvium and older semiconsolidated Tertiary-Quaternary deposits. The lithology of these water-bearing deposits is quite similar and so they are not distinguished from one another in well logs.

For the purpose of this report, the area has been subdivided into two ground water subareas, the San Joaquin Valley and West Side upland subareas. The floor of the valley is underlain by late Quaternary alluvium, and, in the upland, Tertiary-Quaternary sediments are exposed. Thickness of these water-bearing sediments is not known; however, it is probably not very great.

Few water wells exist in this portion of the San Joaquin Valley and, as they are of shallow depth, very little is known with respect to the occurrence and movement of ground water. Ground water in the alluvium probably occurs in unconfined aquifers and that in the Tertiary-Quaternary sediments in confined or partially confined aquifers. Movement of ground water is probably northeastward toward the adjacent Sacramento-San Joaquin Delta. As far as is known, no barrier to the lateral movement of ground water exists in this portion of San Joaquin Valley.

Water Quality. Mineral analyses of water produced from wells indicate that ground water in this portion of Alameda County is of relatively poor quality and suitable only for limited beneficial uses, principally for stock watering.

Small Alluviated Areas

Numerous small alluviated areas flank the mountain creeks in Alameda County. These areas are considered to be too small in surface area to be designated as ground water basins and assigned basin numbers. Plate 2 shows the location of some of these areas and their extent. Still smaller areas exist but they have not been mapped for this investigation. Several small areas are located northeast of Castro Valley along the creeks tributary to San Lorenzo Creek (Plate 2). Other areas are near Midway and Altamont in the northeastern part of the county and in Doolan and Collier Canyons northwest of Livermore.

Occurrence of Ground Water. Water-bearing deposits in these small alluviated areas are very thin and generally consist of stream terraces underlain by nonwater-bearing consolidated rock. Ground water probably occurs in unconfined aquifers and moves in the general direction of the surface slope which is toward the creeks in the center of the valleys and then in a downstream direction. Ground water storage is probably very limited in these thin terrace deposits.

Water Quality. There are limited ground water quality data available with respect to these small alluviated areas. Mineral analyses of water produced from shallow domestic wells indicate that the ground water generally is suitable for most beneficial uses. One well in the vicinity of Altamont contained nitrates in excess of 44 ppm, indicating possible contamination from surface drainage or wastes. Water with boron content of 7.8 ppm was produced from a well in the vicinity of Midway.

CHAPTER III. PRESENT WATER WELL CONSTRUCTION AND SEALING PRACTICES

As a basis for the formulation of well standards to supplement those of a statewide nature, a study was made of prevalent water well construction and sealing practices in Alameda County. In 1956, questionnaires were sent to 23 well drillers operating, or known to have operated, in the county. These questionnaires requested information on materials and methods used and recommendations as to adequate well construction practices. Replies were received from 11 drillers. In addition, a construction survey was made of 267 wells located throughout the county. Wells were inspected to determine: (1) methods and materials used in their construction, (2) their physical condition, (3) sanitary conditions surrounding them, and (4) whether or not adequate provisions had been made to prevent entrance of poor quality water into each well. This information was supplemented by data obtained from "Water Well Drillers Report" forms submitted under provisions of Section 7076 of the Water Code.

Also, during the study of salt-water intrusion in southern Alameda County [13], all available data on wells, both abandoned and active, in the area of salt-water intrusion were compiled and analyzed to determine whether or not wells could be allowing interchange of water between saline and fresh-water-bearing aquifers. The foregoing studies indicated that in many instances methods of well construction and sealing were not adequate to protect the existing ground water from degradation. The following is a summary of present water well construction and sealing practices in Alameda County as shown by the aforementioned studies.

Well Location

The well drillers questionnaire indicated that the majority of drillers in Alameda County are aware of the necessity of considering proximity to sources of contamination when choosing a well site. The replies also indicated that they try to locate wells on high ground and at a safe distance from sources of contamination. Distances recommended by drillers range from 75 feet for privies to 150 feet for cesspools. The well construction survey showed, however, that in practice provisions are usually not made for drainage. Of the wells inspected in the field, 56 percent were constructed with surface drainage toward the well and 13 percent with drainage away from the well. The remaining 31 percent were constructed in level areas or in such a manner that water could pond around the well.

Drilling Methods

The majority of wells in Alameda County are drilled by the cable tool method, with the rotary method used to a much lesser extent. Bored, driven and dug wells are found in the shallow ground water areas of the northern part of the Bay Plain, on the edges of Livermore Valley, and in the smaller alluviated valleys in the mountains.

Casing

Casings are used in the majority of wells drilled or dug in Alameda County. Water-bearing formations in the ground water basins of the county usually are of unconsolidated or semiconsolidated material and require support in the well hole to prevent caving.

Questionnaires returned by drillers indicated that they prefer hard steel pipe of single or double wall thickness manufactured specifically for water well casing. Thickness of casing in relation to well depth and diameter varies considerably, ranging from 14 gage for 4-inch diameter casings at depths less than 100 feet to 3/8-inch for 18-inch or greater diameter casings in wells 700 feet or more in depth. Double casing is also used to increase strength.

Well casings in areas of high saline water such as occur in the area of sea-water intrusion of the Bay Plain frequently are protected from corrosion by a cement grout seal between an inner and outer casing installed for the purpose of preventing movement of saline waters into the lower aquifers. Details of this salinity control seal are discussed in Chapter IV.

It is a general practice in Alameda County to extend casings the full depth of the well hole and seal it in a clay stratum. If such material is not present, a footing of concrete or grout is usually provided.

Eighty percent of the wells inspected during the construction survey had welded casing joints. Other joining methods included use of rivets, bolts, and threaded collars. The casings are generally perforated in place.

Sealing Off Strata

Very limited data are available on practices used in some areas of Alameda County for sealing off strata containing water of undesirable quality. In the Bay Plain, however, it has been found that an annular seal, commonly called a salinity seal, it used to seal off the Newark aquifer which has become degraded by salt water. During the study of salt-water intrusion in this area the construction details of 265 wells, 200 feet deep or greater, were surveyed to determine if they were allowing leakage of water from the Newark to lower aquifers through the well shaft. It was found that 129 of these wells contained salinity seals, 59 of which were considered to be ineffective in preventing interaquifer exchange, and 9 others of questionable effectiveness.

Sanitary Features

Of the wells inspected during the well survey, 58 percent were found which did not have a seal to prevent leakage of surface and shallow, subsurface water down the annular space between the casing and the wall of the well hole. Seals were found in only 9 percent, while in the remaining 33 percent, it was impossible to determine if a seal was present.

Eighty-seven percent of the wells inspected had openings directly into the well casing for the purposes of adding gravel to a gravel-packed well, measuring water levels, providing air release, or other purposes connected with maintenance of the well. In 84 percent of these wells the openings were unprotected against the entrance into the well of pollutants or contaminants. Although the majority of the wells had concrete seals between the casing and the pump pedestal, 81 percent did not have a watertight seal between the pump base and the pedestal or well casing.

Pump houses were noted at 51 percent of the wells observed during the well construction survey. Floor drainage of 59 percent of these houses was toward the well. The use of well pits to accommodate the pumps presents no serious problems, since only two percent of the observed wells had this feature. Twenty-five percent of the wells had faulty lubricating systems, permitting leakage of oil on, or in the immediate vicinity of, the pump.

Six well drillers in the county stated that they disinfect domestic wells after completing construction and installation of the pump. Five drillers stated they never disinfect wells.

Sealing of Abandoned Wells

Only four well drillers of those answering the questionnaire stated that they had permanently sealed abandoned wells. Materials used were equally divided between cement grout, puddled clay and native materials, depending on local conditions. Methods or procedures used in sealing were not given.

During the investigation, thirteen unused wells were inspected in Livermore Valley. Ten of these had been left with open casings or were covered only by a loose metal or wood cover. During the study of salt-water intrusion in the Bay Plain, 68 abandoned wells were found which extended into the lower aquifer. Detailed well tests indicated that 17 of these were allowing degraded water from the Newark aquifer to invade lower aquifers. Other abandoned wells in the Bay Plain were found to be filled with native material; however, none was considered to be adequately sealed.

CHAPTER IV. RECOMMENDED STANDARDS FOR WATER WELL CONSTRUCTION AND SEALING

The basic objective of the following water well construction and sealing standards is to protect the quality of ground water in Alameda County from impairment due to conditions resulting from improperly constructed, defective, or inadequately sealed wells. The standards apply not only to wells being constructed but also to wells that are presently in use and require modification and to wells that are no longer intended to be used and maintained by the owner or that are not considered to be usable, for one or more reasons, and must be destroyed.

Certain geologic, hydrologic, and water quality conditions are similar in all ground water producing areas of California and well construction and sealing standards, with respect to these conditions, are relatively uniform throughout the State. Other conditions are unique to the ground water basins of Alameda County and require that well construction and sealing standards be formulated to supplement the more general statewide standards. Accordingly, this chapter of the report is presented in two parts: (1) General Standards, and (2) Supplemental Standards for Water Quality Problem Areas in Alameda County.

General Standards

A detailed discussion of water well construction and sealing practices used throughout the State of California together with recommended standards are presented in Bulletin No. 74, entitled "Recommended Minimum Well Construction and Sealing Standards for the Protection of Ground Water Quality, State of

California" [14]. The statewide standards are considered to be applicable as general or minimum standards for use in all ground water producing areas of Alameda County. These recommended standards are summarized briefly in the following paragraphs.

Well Location and Sanitary Requirements

Topography and possible sources of contamination must be considered in selecting a well site. Maximum security must be provided against contamination of water in the well from surface or near-surface waters.

All openings into the well casing must be protected from the entrance of surface water or other foreign materials. To prevent surface or shallow, subsurface water from entering and polluting ground water through the annular space surrounding the casing, this space should be sealed to the required depth with impervious material. The required depth depends on the physical characteristics of the underlying material, hydraulic conditions, and depth to usable ground water.

Casing and Annular Space

Well casing is used to support the walls of the drill hole in unconsolidated formations and to prevent the entrance of waters of undesirable quality into the well. The casing must be made of material capable of resisting forces imposed during installation as well as the static forces imposed by the weight of the soil, water, column pipe, and pump. In general, as the depth of well or casing diameter increases, additional forces are imposed necessitating an increase in casing thickness.

Where a well penetrates more than one aquifer and one or more of the aquifers contain water of unsatisfactory quality, the strata which contain this unsatisfactory water shall be prevented from entering aquifers containing water of satisfactory quality.

Well Development

Developing, redeveloping, or conditioning of a well should be done with care and by methods which will not cause damage to the well or cause adverse subsurface conditions that may destroy barriers to the vertical movement of water between aquifers. The latter recommendation is particularly applicable where the quality of water in one of the aquifers is very poor.

Water Quality Sampling

In order to determine the quality of ground water which will be available from the well and its suitability for intended uses, it is recommended that the water in all wells be sampled immediately following construction and development, and appropriate analyses based upon intended uses be made. It may also be advisable to take samples of the water during construction.

Recommended Standards for Destruction of Wells

To destroy an abandoned well, the hole should be filled with cement or drilling mud of adequate viscosity. The casing should be ripped or perforated so that when sealing material is applied, the annular space as well as the casing will be filled with the material. For gravel-packed wells, the sealing material should be applied within the casing, completely filling it, and then forced out under pressure into the gravel envelope.

Water Well Drillers' Report

Submission of a report upon completion of a well or of work on an existing well is required by Sections 7076-7078 of the California Water Code.

Supplemental Standards for Water Quality Problem Areas In Alameda County

In addition to the general statewide standards, supplemental well construction and sealing standards are considered necessary in portions of Alameda County where water quality is a problem. Areas known to have water quality problems in the county are shown on Plate 6. Not all of these problem areas require special standards for well construction and sealing. In many cases, the occurrence of poor quality water is a natural phenomenon, and the presence of a well, regardless of its physical characteristics, would not alter the situation to such an extent that the quality of ground water in adjacent areas would be affected adversely.

General Requirements

In general, problem areas in Alameda County that require supplemental well construction and sealing standards are underlain by ground water in confined aquifers. Confined aquifers containing poor quality water in these areas may underlie and/or overlie other aquifers producing water of satisfactory quality. As these aquifers are often under different hydraulic heads, interchange of water between them due to improperly constructed or inadequately sealed wells is possible. This condition is most critical in the confined ground water areas of the San Leandro, San Lorenzo, and Niles alluvial cones in the Bay Plain. Well construction standards for these areas require provisions to prevent interchange of water between confined aquifers. It is mandatory that these standards apply not only to the construction of new wells but also to existing defective wells. In the Bay Plain, wells are continuing to be found with casings perforated in two or more aquifers (one of which is degraded) or which otherwise allow interchange of saline water between aquifers. As a result, degradation of usable water in the lower aquifers will continue to increase until the upper salt water intruded aquifers are sealed off effectively.

An adequate seal is one which prevents vertical movement of saline water into lower aquifers through the well shaft and/or through the annular space surrounding the shaft. Below are suggested methods for accomplishing this. It should be noted that the effective use of these methods is dependent upon knowledge of the location and extent of the strata to be sealed off. Alternative methods equally as effective and which may be more appropriate for particular field conditions, drilling methods and equipment, may be used in lieu of these methods.

Sealing Off Upper Aquifers. When ground water of undesirable quality overlies an aquifer or aquifers containing usable water in which the well casing is to be perforated, the upper aquifer should be securely sealed off. Plate 4 shows lines of equal depth to the base of the Newark aquifer in the Bay Plain. This aquifer generally contains poor quality water and must be sealed off from underlying aquifers. An effective seal, called a "salinity control seal," has been installed in many wells during construction by drillers in the Niles Cone (Figure 1A). It consist of an outer well casing (conductor casing) that seals off the salin water occurring in the Newark aquifer and an inner casing that penetrates the lower aquifers. The outer casing, which is generally at least four inches larger in diameter than the inner casing, is driven into the thick clay layer underlying the Newark aquifer. The inner casing then is set in place and the space between the two casings filled with sealing material as described under the heading "Sealing Material" in this report (Page 56).

This type of control seal is of particular value when an existing shallow well that has been producing degraded water from the Newark aquifer is to be deepened to obtain better quality water from the lower gravels. It is relatively simple to install a smaller inner casing and extend it to lower aquifers as drilling progresses. After placing the sealing material between the two casings, the inner casing is perforated adjacent to the lower aquifers.

Sealing Off Intermediate Aquifers. When an aquifer containing undesirable water lies between two aquifers containing usable water in which the well casing is to be perforated, the annular spaces opposite the confining strata above and below this aquifer must be sealed.

If the sealing is to be done during construction of a well, the well hole should be drilled and the well casing driven in but not completely through the confining stratum overlying the

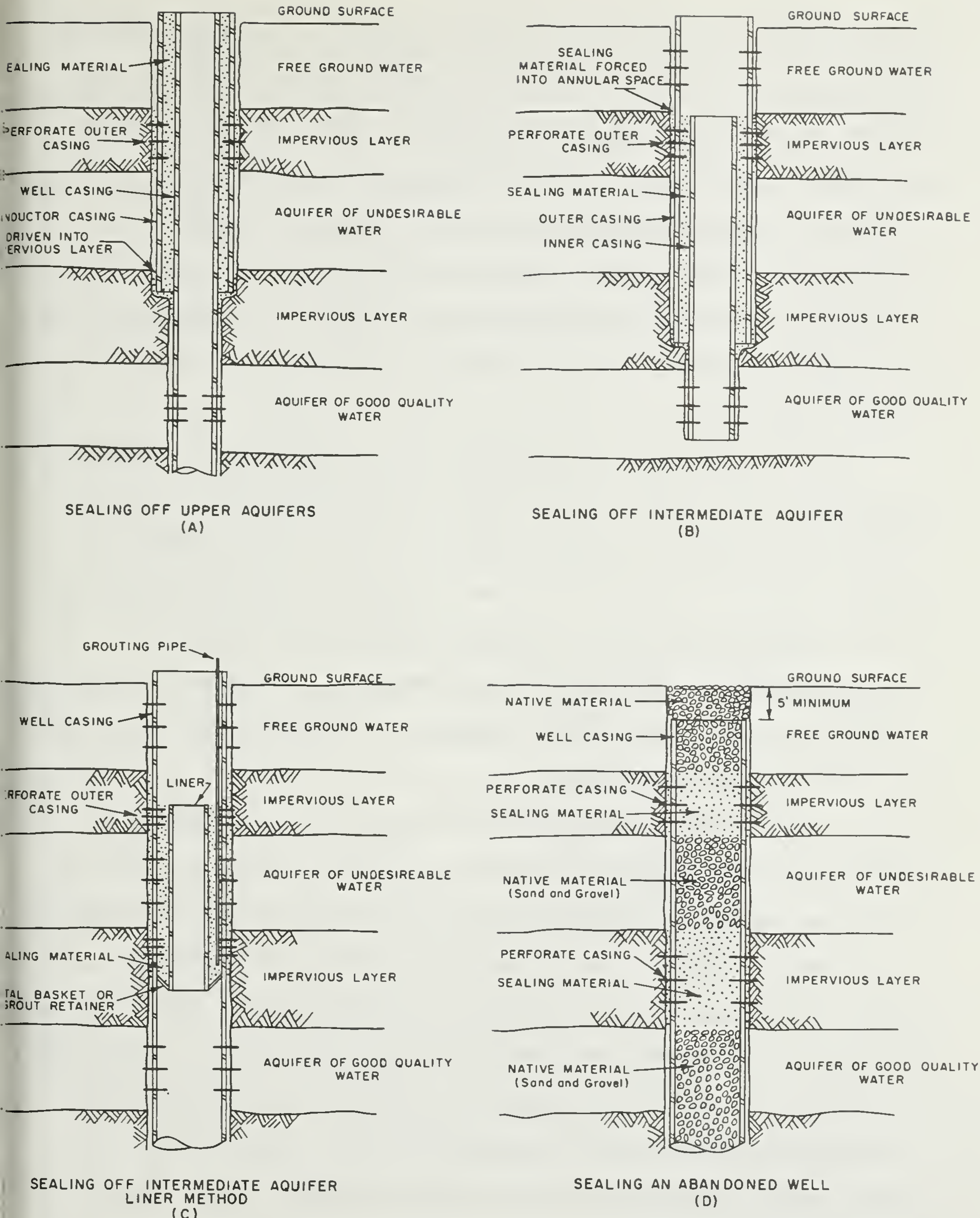

Figure I. TYPICAL SEALING METHODS

lower aquifer containing good quality water. A smaller diameter casing is then extended, during the course of the drilling, any desired distance into the lower aquifer. After perforating the well casing opposite the upper confining stratum, the top of the smaller casing is brought to an elevation which overlaps the perforations (Figure 1B). The space between the two casings is then filled by means of a grouting pipe with sealing material and sufficient pressure applied to force the material out into the annular space.

If sealing is to take place in an existing well which is to be deepened to draw water from a lower aquifer, the casing opposite the intervals to be sealed is perforated. A packer or similar device is placed below the perforations and, as described above, a smaller diameter casing is installed, the space between the two casings filled with sealing material, and pressure applied to the material. The smaller casing is extended to the desired depth in the deepened well.

An alternative method of sealing is as follows. A section of liner casing is placed in the well casing so that it extends at least 10 feet above and below the perforated interval to be sealed (Figure 1C). A retaining seal (rubber gasket, "petal basket" or similar device) is placed at the bottom of the annular space between the liner and the well casing. A grout pipe is extended in the annular space to the bottom of the interval to be sealed and the space filled with grout. The grout pipe should remain submerged in the sealing material during the placement of the seal.

Destruction of Wells. Many wells have been found in Alameda County where no pump is attached and where prolonged disuse is clearly evident. In some instances, the surrounding area has become overgrown with weeds and the well, if left open, may be filled with debris and possibly the decaying carcasses of small animals. Other wells have been covered over by new construction, such as subdivisions, paved streets, parking lots and buildings. These wells, unattended and in disrepair, their casings often badly corroded or even collapsed, may serve as conduits for the admixture of poor quality water with water of good and usable quality. It is imperative, therefore, that these wells be searched out and destroyed in order to achieve adequate protection of the ground water supplies.

The principle of destroying a well is restoration of the controlling geological conditions as nearly as possible to those which existed prior to construction of the well. This requires placement of a seal of impermeable material in the well casing and, if needed, in the annular space surrounding the casing adjacent to all clay layers which separate and prevent movement of water between aquifers. To be sure that the annular spaces adjacent to the clay layers are sealed, it is often necessary to rip or perforate the casing in these intervals to allow fluid sealing material to move outward from the well shaft during placement. Procedures to follow to insure an adequate seal are:

1. If a well pump is present, remove the pump, pump column, bowl assembly, etc., from the well shaft and inspect the well to determine well construction details and to

insure freedom from obstructions that may prevent adequate sealing. If necessary, the well should be redrilled or cleaned out to a depth extending to at least 20 feet into the lower clay layer which is to be sealed off.

2. Perforate the well casing in lengths of at least 10 feet opposite the clay layers (Figure 1D).

3. Fill the well casing from the bottom of the well to the bottom of the lower perforations with sand, gravel or other suitable material. Place sealing material in the perforated interval or intervals, and sand, gravel or other suitable material from the top of the perforations to the ground surface. If desired for practical reasons, the entire well may be filled with sealing material with the exception of the upper five feet. Sufficient sealing material should be placed to occupy at least 130 percent of the volume of the well casing in the interval or intervals to be sealed. No materials containing organic residues should be used. The sealing material shall be placed with a grouting pipe which extends to the bottom of the interval to be sealed and pumped into the pipe continuously until it displaces water in the well and fills up the casing in this interval.

4. Removal of the casing from the ground surface to a depth of 5 feet may be desired; in any case, the hole remaining should be filled with sand and/or gravel.

Sealing Material. Sealing material shall consist of cement and water, cement grout, or other material of equal strength and watertightness. The cement and water mixture shall be composed of one bag of cement (94 pounds) to 5 to 7-1/2 gallons of water. Cement grout shall be composed of not more than two parts of sand and one part of cement to 5 to 7-1/2 gallons of water per bag of cement.

To facilitate handling and setting of grout or cement and water, commercial additives may be used provided they do not exceed 10 percent of the volume of cement. Calcium chloride, however, must be limited to less than 2 pounds per sack of cement.

Sealing materials shall be placed in the interval or intervals to be sealed by methods that prevent free fall, dilution, and separation.

When pressure is applied to force sealing material into the annular space, the pressure shall be maintained for a length of time sufficient for the cement sealing mixture to set. Time of set for cement mixture shall be at least 24 hours and preferably 72 hours before drilling is resumed, depending on the admixture used.

Standards for Specific Water Quality Problem Areas

Areas in Alameda County requiring supplemental well construction and sealing standards are primarily the Bay Plain and Livermore Valley ground water basin. Certain small alluviated areas may require careful construction with regard to sanitary features.

Bay Plain. Areas in which the upper aquifers of the San Leandro and San Lorenzo alluvial cones and the Newark and Centerville aquifers of the Niles Cone produce ground water having a high chloride concentration are shown on Plate 6. These are areas where fresh-water aquifers have been intruded by sea water, which in 1961 had advanced inland as far as the Hayward fault, approximately two miles east of Centerville.

Therefore, in wells penetrating the lower aquifers in all portions of the San Leandro, San Lorenzo, and Niles alluvial cones, the upper aquifers should be sealed off from the lower aquifers. A suggested sealing method is presented under "Sealing Off Upper Aquifers", or if the well is to be abandoned, "Sealing Abandoned Wells."

The Centerville aquifer is considered degraded in those areas of the Niles Cone where it is known to produce water containing more than 150 ppm chlorides. In these areas, the Centerville aquifer must be sealed off from the overlying upper (Newark) aquifer and from all underlying aquifers during the construction or correction of a well or the sealing of an abandoned well. A suggested sealing method is presented under "Sealing Off Intermediate Aquifers," or "Sealing Abandoned Wells."

In the vicinity of Alvarado and in localized areas of the Niles Cone, one or more aquifers underlying the Centerville aquifer contain poor quality water. These aquifers must be sealed off from all underlying and overlying aquifers during well construction or sealing.

Perched or semiperched ground water of poor quality exists in a limited area northwest of Decoto, as shown on Plate 6. This poor quality water probably can be sealed off from underlying aquifers by installing an annular seal in the space around the well casing adjacent to the zone of perched water.

Livermore Valley Ground Water Basin. In the eastern part of Livermore Valley ground water basin, water should be sampled and analyzed frequently during the construction of deep wells and the water surface in the well observed closely. If poor quality water is found to be entering the well at depth under pressure (shown by a marked rise in water surface), it should be sealed off to prevent degradation of the overlying reservoir of usable ground water.

Small Alluviated Areas. There are very limited water quality data on the small alluviated areas flanking the mountain creeks in Alameda County. Several of these small valley-fill areas along the creeks tributary to San Lorenzo Creek are relatively heavily populated. There are septic tanks in these areas and small wells producing water for domestic purposes. As the water-bearing deposits are very thin and of limited areal extent, the contamination of well water by effluent from a nearby septic tank is possible. In these areas, it is a necessity that the sanitary features of well construction recommended in Bulletin No. 74, be closely observed.

CHAPTER V. CONCLUSIONS AND RECOMMENDATIONS

As a result of the studies and investigations leading to the preparation of this report, the following conclusions and recommendations are made:

Conclusions

(1) The survey of water well construction and sealing practices combined with the ground water quality studies in Alameda County reported in this bulletin, and the results of our salt-water intrusion study in southern Alameda County [13], indicate that in many instances present methods of well construction and sealing are not adequate to protect the quality of ground water from degradation.

(2) There are five principal ground water producing areas in Alameda County. These are the Bay Plain of the Santa Clara Valley ground water basin; the Livermore Valley, Sunol Valley, and Castro Valley ground water basins; and a portion of the San Joaquin Valley ground water basin. In addition, there are a number of small alluviated areas flanking some of the mountain creeks of the county and producing limited amounts of ground water. These small areas are considered to be too minor in areal extent to be classified as ground water basins in this report.

(3) Ground water occurs in both confined and unconfined aquifers in the water-bearing deposits of Alameda County. Thick, extensive blue clay layers confine ground water under pressure in several fairly well defined gravel layers beneath most of the Bay Plain. In Livermore Valley, unconfined aquifers occur in

the Livermore subbasin and in the southern part of the Santa Rita subbasin. Aquifers underlying the remainder of the valley floor are confined. In general, ground water occurs in unconfined aquifers in the remainder of the ground water basins of Alameda County (Plate 3). Ground water in unconfined aquifers is probably underlain by confined aquifers in portions of the Livermore Valley and Sunol Valley basins.

(4) Ground water in Alameda County is generally of satisfactory mineral quality for most beneficial uses. However, certain portions of the principal ground water basins contain poor quality water which is unsuitable or undesirable for some uses (Plate 6).

(5) The major problem area with respect to the need for water well construction and sealing standards is located in the southern part of the Bay Plain. Water quality problems in the Livermore Valley ground water basin appear to be of lesser extent with respect to construction and sealing of water wells. In addition, small and local areas of poor quality water are found in other ground water basins within the county. The small alluviated areas flanking mountain creeks are considered to be potential problem areas with respect to sanitary conditions.

(6) In order to prevent continued degradation of ground water through improperly constructed and abandoned water wells in Alameda County, adequate water well construction and sealing standards must be employed. In addition, existing water wells which are causing water quality degradation must be corrected to conform to such standards.

Recommendations

It is recommended that the San Francisco Bay Regional Water Pollution Control Board urge:

1. Alameda County to adopt and enforce, at the earliest possible date, adequate water well construction and sealing standards for the protection of ground water quality.
2. That the information presented in Bulletin No. 74[14] and in this bulletin be used as a guide in developing such standards.
3. Responsible agencies in Alameda County to continue and expand the investigational work leading to the identification and correction of existing improperly constructed and abandoned water wells.

Because of the importance of protecting water quality in the ground water basins covered in this report, it is requested that Alameda County keep the San Francisco Bay Regional Water Pollution Control Board and this department informed of progress in the implementation of these recommendations.

APPENDIX A

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BIBLIOGRAPHY

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APPENDIX B

WATER QUALITY CRITERIA

WATER QUALITY CRITERIA

Criteria presented in the following sections can be utilized in evaluating mineral quality of water relative to existing or anticipated beneficial uses. It should be noted that these criteria are merely guides to the appraisal of water quality. Except for those constituents which are considered toxic to human beings, these criteria should be considered as suggested limiting values. Water which exceeds one or more of these limiting values need not be eliminated from consideration as a source of supply, but other sources of better quality water should be investigated.

Criteria for Drinking Water

Criteria for appraising the suitability of water for domestic and municipal use in connection with interstate quarantine have been promulgated by the United States Public Health Service. The limiting concentrations of chemical substances in drinking water have been abstracted from these criteria and are shown in Table B-1. Other organic or mineral substances may be limited if their presence renders the water hazardous for use.

Interim standards for certain mineral constituents have been adopted by the California State Board of Public Health. Based on these standards, temporary permits may be issued for drinking water supplies failing to meet the United States Public Health Service Drinking Water Standards, provided the mineral constituents in Table B-2 are not exceeded.

TABLE B-1

UNITED STATES PUBLIC HEALTH SERVICE
DRINKING WATER STANDARDS
1962

Chemical Substance	Mandatory limit in ppm
Arsenic (As)	0.05
Barium (Ba)	1.0
Cadmium (Cd)	0.01
Hexavalent chromium (Cr^{+6})	0.05
Cyanide (CN)	0.2
Lead (Pb)	0.05
Selenium (Se)	0.01
Silver (Ag)	0.05

	Nonmandatory, but recommended limit in ppm
Alkyl benzene sulphonate (detergent)	0.5
Arsenic (As)	0.01
Carbon chloroform extract (exotic organic chemicals)	0.2
Chloride (Cl)	250
Copper (Cu)	1.0
Cyanide (CN)	0.01
Fluoride (F) (See Table B-3)	1.7
Iron (Fe)	0.3
Manganese (Mn)	0.05
Nitrate (NO_3)	45
Phenols	0.001
Sulfate (SO_4)	250
Total dissolved solids (TDS)	500
Zinc (Zn)	5

TABLE B-2

UPPER LIMITS OF TOTAL SOLIDS AND SELECTED MINERALS IN DRINKING WATER AS DELIVERED TO THE CONSUMER

	Permit	Temporary Permit
Total solids	500 (1000)*	1500 ppm
Sulfates (SO_4)	250 (500)*	600 ppm
Chlorides (Cl)	250)500)*	600 ppm
Magnesium (Mg)	125 (125)	150 ppm

* Numbers in parentheses are maximum permissible, to be used only where no other more suitable water is available in sufficient quantity for use in the system.

The relationship of infant methemoglobinemia (a reduction of oxygen content in the blood, constituting a form of asphyxia) to nitrates in the water supply has led to limitation of nitrates in drinking water. The California State Department of Public Health has recommended a tentative limit of 10 ppm nitrogen (44 ppm nitrates) for domestic water. Water containing higher concentrations of nitrates may be considered to be of questionable quality for domestic and municipal use.

The California State Board of Public Health has defined th maximum safe amounts of fluoride ion in drinking water in relation to mean annual temperature. These relationships are shown in Table B-3.

TABLE B-3

RELATIONSHIP OF TEMPERATURE TO FLUORIDE CONCENTRATION IN DRINKING WATER

Mean annual Temperature	Mean monthly fluoride ion concentration
50°F	1.5 ppm
60°F	1.0 ppm
70°F - above	0.7 ppm

Criteria for Hardness

Even though hardness in water is not included in the foregoing standards, it is of importance in domestic and industrial uses. Excessive hardness in water used for domestic purposes causes increased consumption of soap and formation of scale in pipe and fixtures. Table B-4 showing degrees of hardness in water has been suggested by the United States Geological Survey:

TABLE B-4

HARDNESS CLASSIFICATION

Range of hardness, expressed as $CaCO_3$ in ppm	Relative classification
0 - 60	Soft
61 - 120	Moderately hard
121 - 200	Hard
Greater than 200	Usually requires softening

Criteria for Irrigation Water

Criteria for mineral quality of irrigation water have been developed by the Regional Salinity Laboratories of the United States Department of Agriculture in cooperation with the University of California. Because of diverse climatological conditions and the variation in crops and soils in California, only general limits of quality for irrigation waters can be suggested. The department uses three broad classifications of irrigation waters as listed below and in Table B-5.

Class 1 - Regarded as safe and suitable for most Plants under most conditions of soil and climate.

Class 2 - Regarded as possibly harmful for certain crops under certain conditions of soil or climate, particularly in the higher ranges of this class.

Class 3 - Regarded as probably harmful to most crops and unsatisfactory for all but the most tolerant.

TABLE B-5

QUALITATIVE CLASSIFICATION OF IRRIGATION WATERS

Chemical properties	Class 1 Excellent to good	Class 2 Good to injurious	Class 3 Injurious to Unsatisfactory
Total dissolved solids, in ppm	Less than 700	700 - 2000	More than 2000
Conductance, in micromhos at 25°C	Less than 1000	1000 - 3000	More than 3000
Chlorides, in ppm	Less than 175	175 - 350	More than 350
Sodium, in percent of base constituents	Less than 60	60 - 75	More than 75
Boron, in ppm	Less than 0.5	0.5 - 2.0	More than 2.0

These criteria have limitations in actual practice. In many instances water may be wholly unsuitable for irrigation under certain conditions of use, and yet be completely satisfactory under other circumstances. Consideration also should be given to soil permeability, drainage, temperature, humidity, rainfall, and other conditions that can alter the response of a crop to a particular quality of water.

Criteria for Industrial Uses

It is beyond the scope of this report to present water quality requirements for the numerous types of industry found in Alameda County or for the diverse processes within these industries, since such criteria are as varied as industry itself. Food processing, beverage production, pulp and paper manufacturing, and textile industries have exacting requirements, while poor quality water can be used for some cooling or metallurgical operations. In general, where a water supply meets drinking water standards, it is satisfactory for industrial use, either directly or following a limited amount of treatment or softening by the industry.

APPENDIX C

MINERAL CLASSIFICATION OF WATERS

Mineral Classification of Waters

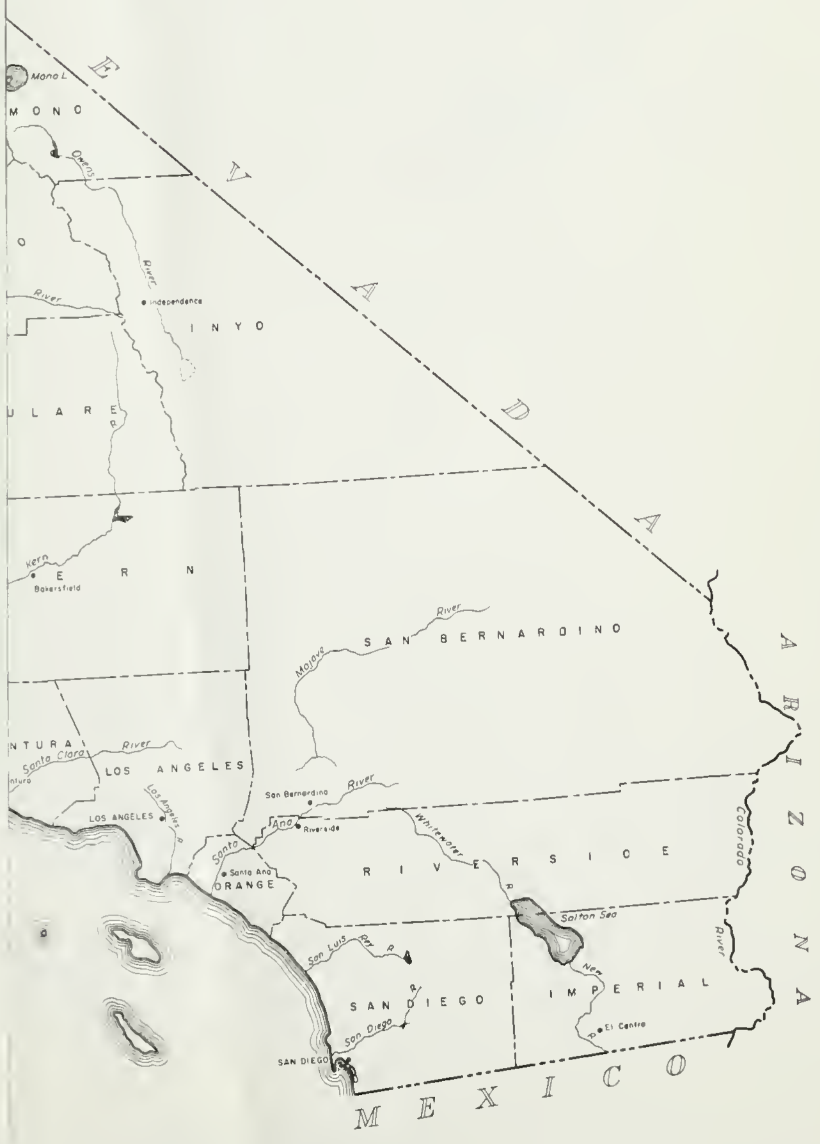
Water is classified, with respect to mineral conposition, in terms of predominant ions. Specifically, the name of an ion is used where its chemical equivalent constitutes half or more of the total for its appropriate ionic group. Where no one ion fulfills this requirement, a hyphenated combination of the two most abundant ions is used, named in order of abundance. Thus, water in which the calcium ion constitutes half or more of the cations and the bicarbonate ion amounts to half or more of the anions, expressed in equivalent weights, is called calcium bicarbonate water. Where calcium, though predominant, is less than half and sodium next in abundance, the name is modified to calcium-sodium bicarbonate. This method of classification enables rapid, though rough, comparisons to be made, regardless of the relative mineral concentrations of the waters under consideration.

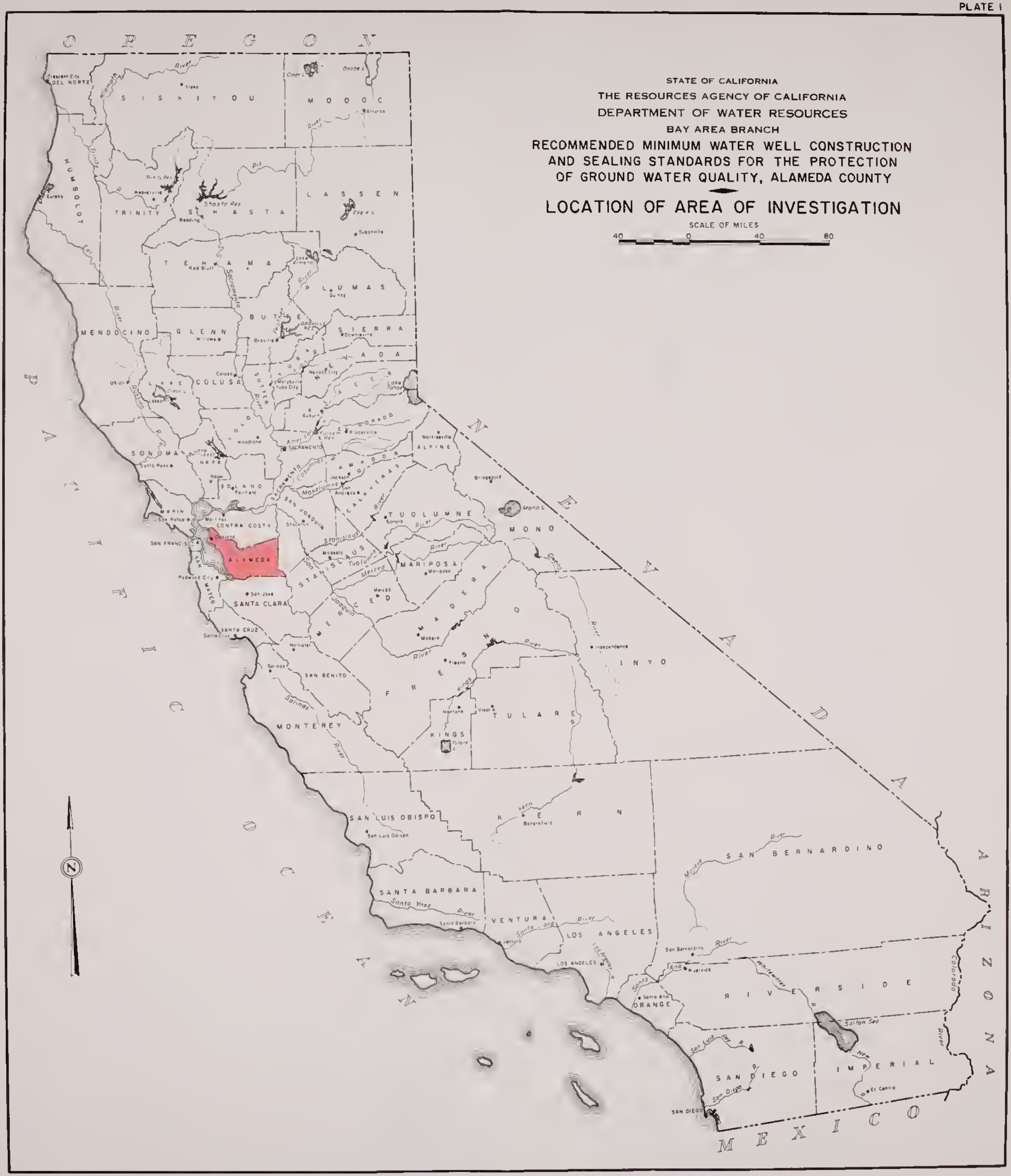
STATE OF CALIFORNIA
THE RESOURCES AGENCY OF CALIFORNIA
DEPARTMENT OF WATER RESOURCES
BAY AREA BRANCH

RECOMMENDED MINIMUM WATER WELL CONSTRUCTION AND SEALING STANDARDS FOR THE PROTECTION OF GROUND WATER QUALITY, ALAMEDA COUNTY

LOCATION OF AREA OF INVESTIGATION

SCALE OF MILES
40 0 40 80

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DEPARTMENT OF WATER RESOURCES
BAY AREA BRANCH
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LOCATION OF AREA OF INVESTIGATION
SCALE OF MILES
40 0 40 80
OREGON
NEVADA
ARIZONA
MEXICO
PACIFIC OCEAN
SISKIYOU
MODOC
HUMBOLDT
TRINITY
SHASTA
LASSEN
TEHAMA
PLUMAS
BUTTE
MENDOCINO
GLENN
SIERRA
NEVADA
COLUSA
LAKE
SUTTER
YUBA
PLACER
YOLO
SONOMA
NAPA
SOLANO
SACRAMENTO
EL DORADO
ALPINE
AMADOR
CALAVERAS
MARIN
CONTRA COSTA
SAN JOAQUIN
TUOLUMNE
MONO
SAN FRANCISCO
ALAMEDA
STANISLAUS
MARIPOSA
SAN MATEO
SANTA CLARA
MERCED
MADERA
SANTA CRUZ
FRESNO
INYO
SAN BENITO
MONTEREY
KINGS
TULARE
SAN LUIS OBISPO
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VENTURA
LOS ANGELES
ORANGE
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IMPERIAL
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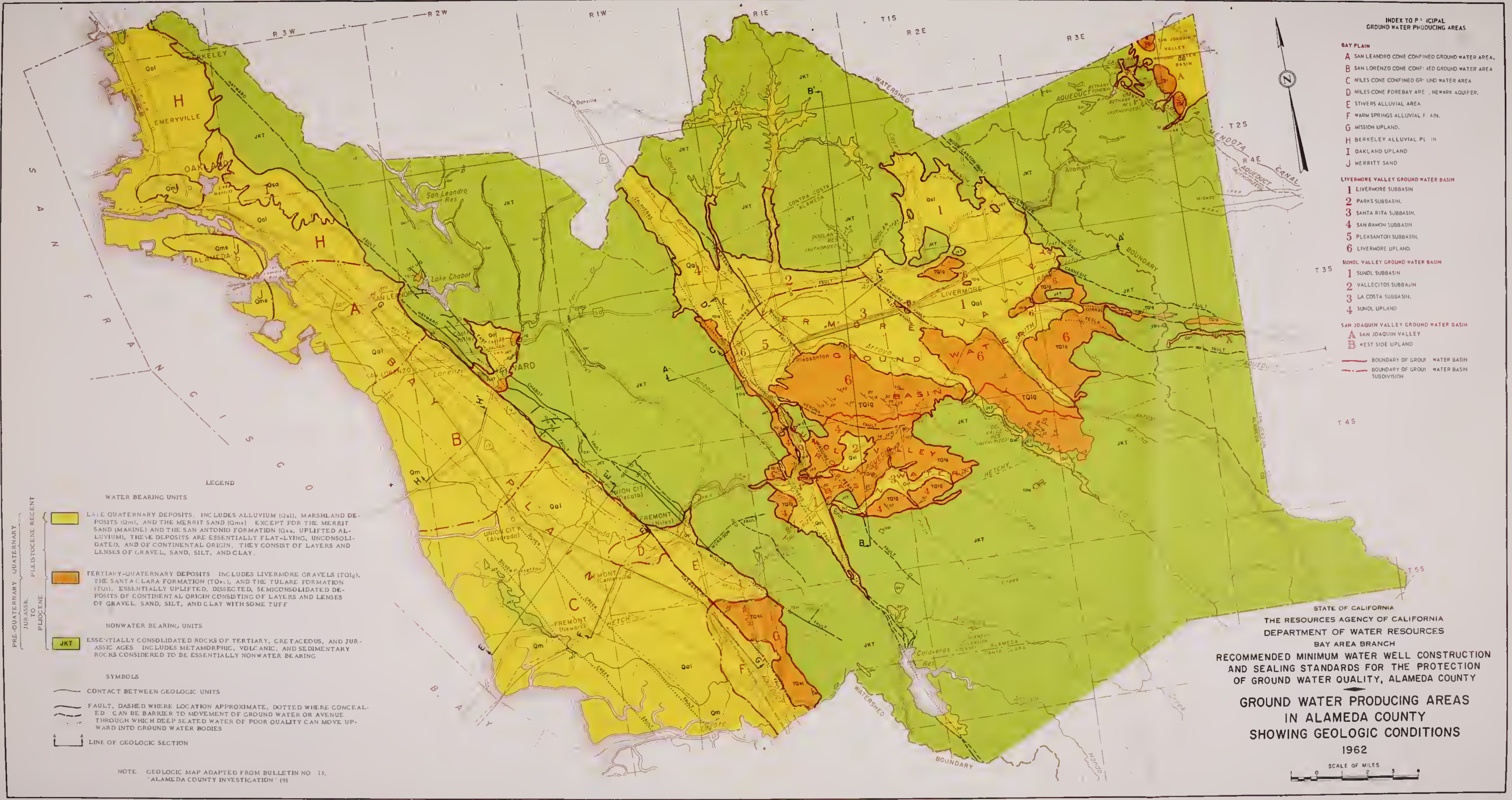
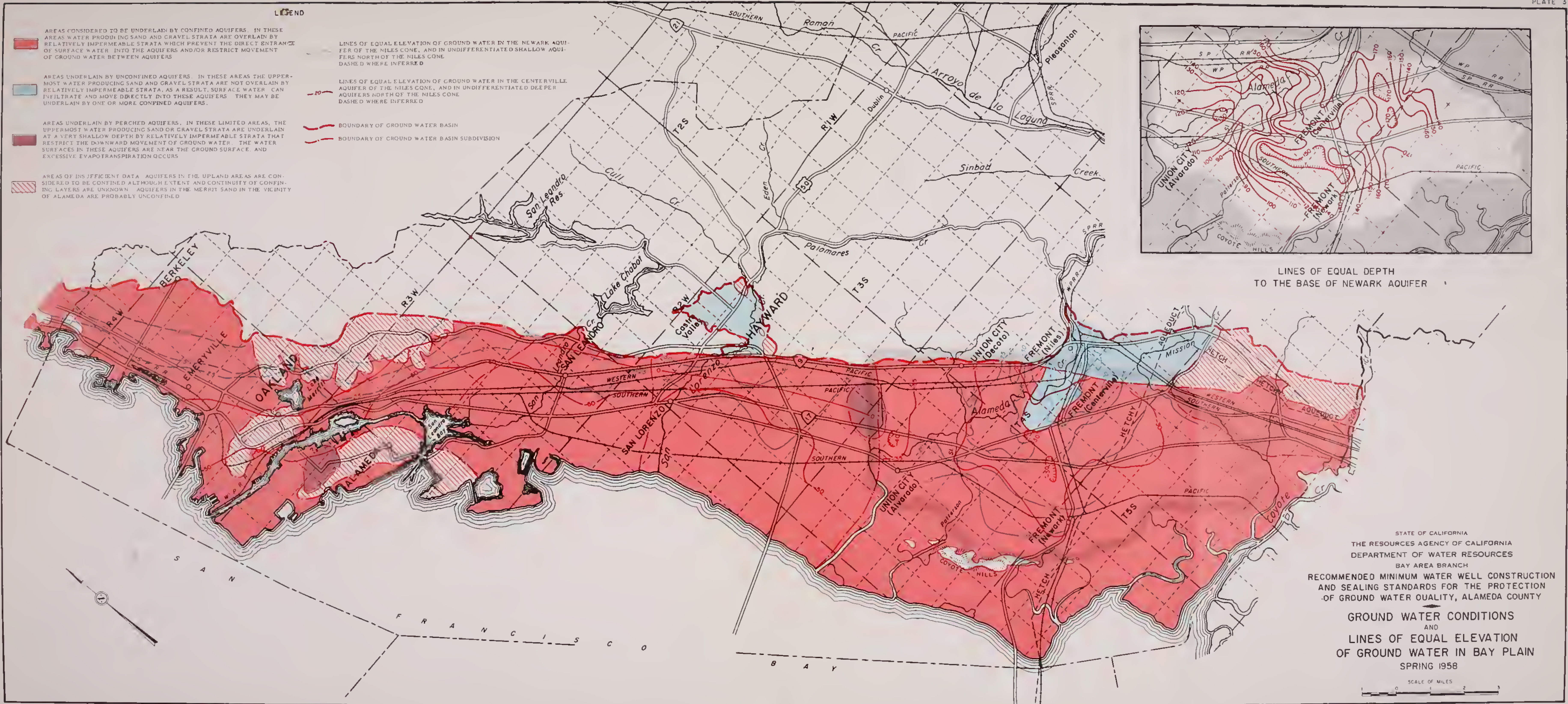

INDEX TO PRINCIPAL
GROUND WATER PRODUCING AREAS
BAY PLAIN
A SAN LEANDRO CONE CONFINED GROUND WATER AREA.
B SAN LORENZO CONE CONFINED GROUND WATER AREA
C NILES CONE CONFINED GROUND WATER AREA
D NILES CONE FOREBAY AREA, NEWARK AQUIFER.
E STIVERS ALLUVIAL AREA
F WARM SPRINGS ALLUVIAL PLAIN.
G MISSION UPLAND.
H BERKELEY ALLUVIAL PLAIN
I OAKLAND UPLAND
J MERRITT SAND
LIVERMORE VALLEY GROUND WATER BASIN
1 LIVERMORE SUBBASIN
2 PARKS SUBBASIN.
3 SANTA RITA SUBBASIN.
4 SAN RAMON SUBBASIN
5 PLEASANTON SUBBASIN.
6 LIVERMORE UPLAND.
SUNOL VALLEY GROUND WATER BASIN
1 SUNOL SUBBASIN
2 VALLECITOS SUBBASIN
3 LA COSTA SUBBASIN.
4 SUNOL UPLAND
SAN JOAQUIN VALLEY GROUND WATER BASIN
A SAN JOAQUIN VALLEY
B WEST SIDE UPLAND
BOUNDARY OF GROUND WATER BASIN
BOUNDARY OF GROUND WATER BASIN SUBDIVISION
LEGEND
WATER BEARING UNITS
PRE-QUATERNARY QUATERNARY
JURASSIC TO PLIOCENE
PLEISTOCENE RECENT
LATE QUATERNARY DEPOSITS. INCLUDES ALLUVIUM (Qal), MARSHLAND DEPOSITS (Qm), AND THE MERRIT SAND (Qms). EXCEPT FOR THE MERRIT SAND (MARINE) AND THE SAN ANTONIO FORMATION (Qsa, UPLIFTED ALLUVIUM), THESE DEPOSITS ARE ESSENTIALLY FLAT-LYING, UNCONSOLIDATED, AND OF CONTINENTAL ORIGIN. THEY CONSIST OF LAYERS AND LENSES OF GRAVEL, SAND, SILT, AND CLAY.
TERTIARY-QUATERNARY DEPOSITS. INCLUDES LIVERMORE GRAVELS (TQlg), THE SANTA CLARA FORMATION (TQsc), AND THE TULARE FORMATION (TQt). ESSENTIALLY UPLIFTED, DISSECTED, SEMICONSOLIDATED DEPOSITS OF CONTINENTAL ORIGIN CONSISTING OF LAYERS AND LENSES OF GRAVEL, SAND, SILT, AND CLAY WITH SOME TUFF
NONWATER BEARING UNITS
JKT
ESSENTIALLY CONSOLIDATED ROCKS OF TERTIARY, CRETACEOUS, AND JURASSIC AGES. INCLUDES METAMORPHIC, VOLCANIC, AND SEDIMENTARY ROCKS CONSIDERED TO BE ESSENTIALLY NONWATER BEARING
SYMBOLS
CONTACT BETWEEN GEOLOGIC UNITS
FAULT, DASHED WHERE LOCATION APPROXIMATE, DOTTED WHERE CONCEALED. CAN BE BARRIER TO MOVEMENT OF GROUND WATER OR AVENUE THROUGH WHICH DEEP SEATED WATER OF POOR QUALITY CAN MOVE UPWARD INTO GROUND WATER BODIES
LINE OF GEOLOGIC SECTION
NOTE: GEOLOGIC MAP ADAPTED FROM BULLETIN NO. 13, "ALAMEDA COUNTY INVESTIGATION" (9)
SAN FRANCISCO BAY
BERKELEY
EMERYVILLE
OAKLAND
ALAMEDA
SAN LEANDRO
SAN LORENZO
HAYWARD
UNION CITY (Decoto)
UNION CITY (Alvarado)
FREMONT (Niles)
FREMONT (Centerville)
FREMONT (Newark)
Pleasanton
LIVERMORE
Lake Chabot
San Leandro Res
Calaveras Res
LIVERMORE VALLEY GROUND WATER BASIN
SUNOL VALLEY GROUND WATER BASIN
BAY PLAIN
R 3 W
R 2 W
R 1 W
R 1 E
R 2 E
R 3 E
R 4 E
T 1 S
T 2 S
T 3 S
T 4 S
T 5 S
STATE OF CALIFORNIA
THE RESOURCES AGENCY OF CALIFORNIA
DEPARTMENT OF WATER RESOURCES
BAY AREA BRANCH
RECOMMENDED MINIMUM WATER WELL CONSTRUCTION AND SEALING STANDARDS FOR THE PROTECTION OF GROUND WATER QUALITY, ALAMEDA COUNTY
GROUND WATER PRODUCING AREAS IN ALAMEDA COUNTY SHOWING GEOLOGIC CONDITIONS
1962
SCALE OF MILES
0 1 2 3 4


LEGEND
AREAS CONSIDERED TO BE UNDERLAIN BY CONFINED AQUIFERS. IN THESE AREAS WATER PRODUCING SAND AND GRAVEL STRATA ARE OVERLAIN BY RELATIVELY IMPERMEABLE STRATA WHICH PREVENT THE DIRECT ENTRANCE OF SURFACE WATER INTO THE AQUIFERS AND/OR RESTRICT MOVEMENT OF GROUND WATER BETWEEN AQUIFERS
AREAS UNDERLAIN BY UNCONFINED AQUIFERS. IN THESE AREAS THE UPPERMOST WATER PRODUCING SAND AND GRAVEL STRATA ARE NOT OVERLAIN BY RELATIVELY IMPERMEABLE STRATA. AS A RESULT, SURFACE WATER CAN INFILTRATE AND MOVE DIRECTLY INTO THESE AQUIFERS. THEY MAY BE UNDERLAIN BY ONE OR MORE CONFINED AQUIFERS.
AREAS UNDERLAIN BY PERCHED AQUIFERS. IN THESE LIMITED AREAS, THE UPPERMOST WATER PRODUCING SAND OR GRAVEL STRATA ARE UNDERLAIN AT A VERY SHALLOW DEPTH BY RELATIVELY IMPERMEABLE STRATA THAT RESTRICT THE DOWNWARD MOVEMENT OF GROUND WATER. THE WATER SURFACES IN THESE AQUIFERS ARE NEAR THE GROUND SURFACE, AND EXCESSIVE EVAPOTRANSPIRATION OCCURS
AREAS OF INSUFFICIENT DATA. AQUIFERS IN THE UPLAND AREAS ARE CONSIDERED TO BE CONFINED ALTHOUGH EXTENT AND CONTINUITY OF CONFINING LAYERS ARE UNKNOWN. AQUIFERS IN THE MERRIT SAND IN THE VICINITY OF ALAMEDA ARE PROBABLY UNCONFINED
LINES OF EQUAL ELEVATION OF GROUND WATER IN THE NEWARK AQUIFER OF THE NILES CONE, AND IN UNDIFFERENTIATED SHALLOW AQUIFERS NORTH OF THE NILES CONE
DASHED WHERE INFERRED
20
LINES OF EQUAL ELEVATION OF GROUND WATER IN THE CENTERVILLE AQUIFER OF THE NILES CONE, AND IN UNDIFFERENTIATED DEEPER AQUIFERS NORTH OF THE NILES CONE
DASHED WHERE INFERRED
BOUNDARY OF GROUND WATER BASIN
BOUNDARY OF GROUND WATER BASIN SUBDIVISION
LINES OF EQUAL DEPTH TO THE BASE OF NEWARK AQUIFER
BERKELEY
EMERYVILLE
OAKLAND
ALAMEDA
SAN LEANDRO
SAN LORENZO
HAYWARD
Castro Valley
UNION CITY (Decoto)
UNION CITY (Alvarado)
FREMONT (Niles)
FREMONT (Centerville)
FREMONT (Newark)
Pleasanton
Dublin
San Leandro Res.
Lake Chabot
Cull Cr.
Palomares Cr.
Sinbad Creek
Arroyo de la Laguna
Alameda Cr.
Coyote Cr.
Patterson
COYOTE HILLS
Mission
HETCH HETCHY AQUEDUCT
SOUTHERN PACIFIC
WESTERN PACIFIC
T2S
T3S
T4S
T5S
R4W
R3W
R2W
R1W
SAN FRANCISCO BAY
STATE OF CALIFORNIA
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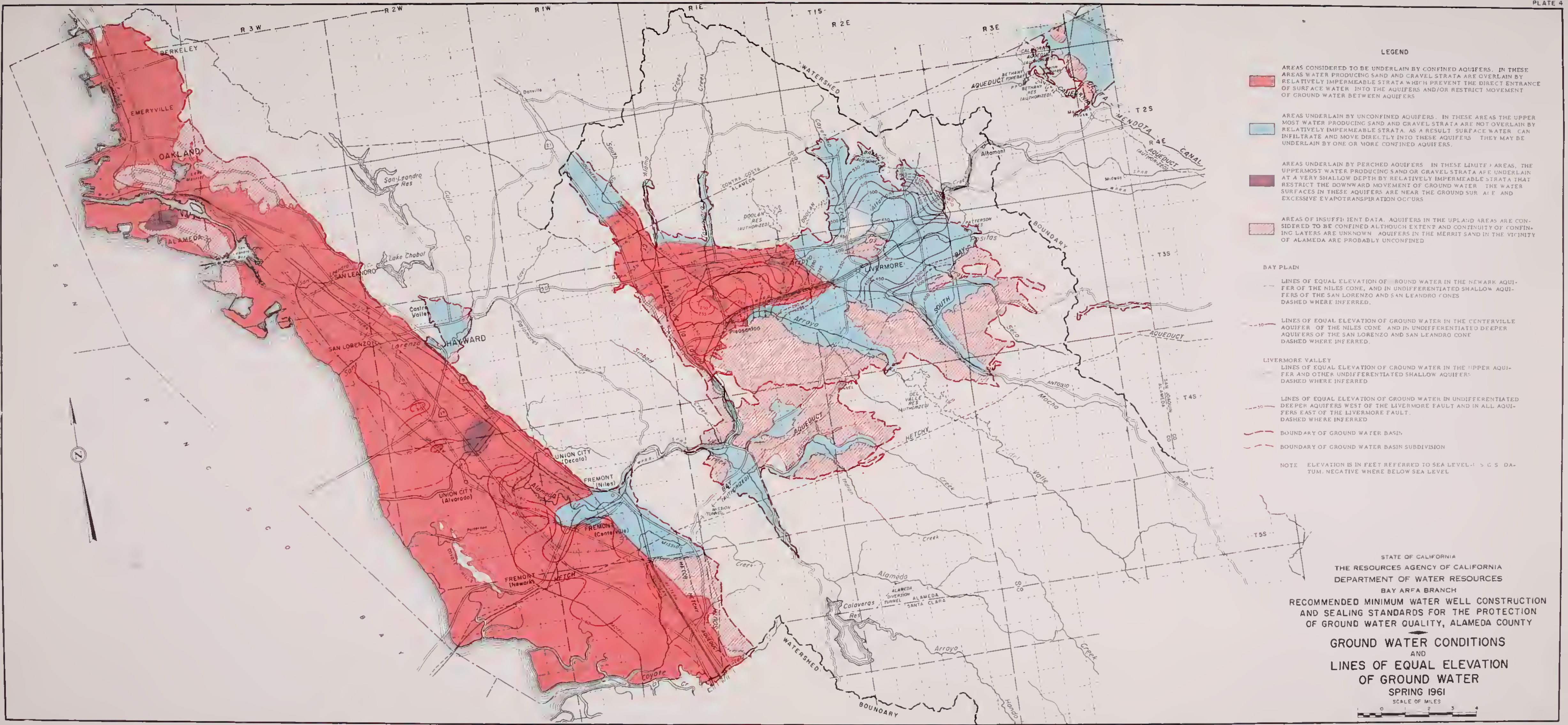
DEPARTMENT OF WATER RESOURCES
BAY AREA BRANCH
RECOMMENDED MINIMUM WATER WELL CONSTRUCTION AND SEALING STANDARDS FOR THE PROTECTION OF GROUND WATER QUALITY, ALAMEDA COUNTY
GROUND WATER CONDITIONS
AND
LINES OF EQUAL ELEVATION
OF GROUND WATER IN BAY PLAIN
SPRING 1958
SCALE OF MILES
1 0 1 2 3


LEGEND
AREAS CONSIDERED TO BE UNDERLAIN BY CONFINED AQUIFERS. IN THESE AREAS WATER PRODUCING SAND AND GRAVEL STRATA ARE OVERLAIN BY RELATIVELY IMPERMEABLE STRATA WHICH PREVENT THE DIRECT ENTRANCE OF SURFACE WATER INTO THE AQUIFERS AND/OR RESTRICT MOVEMENT OF GROUND WATER BETWEEN AQUIFERS
AREAS UNDERLAIN BY UNCONFINED AQUIFERS. IN THESE AREAS THE UPPER MOST WATER PRODUCING SAND AND GRAVEL STRATA ARE NOT OVERLAIN BY RELATIVELY IMPERMEABLE STRATA. AS A RESULT SURFACE WATER CAN INFILTRATE AND MOVE DIRECTLY INTO THESE AQUIFERS THEY MAY BE UNDERLAIN BY ONE OR MORE CONFINED AQUIFERS.
AREAS UNDERLAIN BY PERCHED AQUIFERS IN THESE LIMITED AREAS, THE UPPERMOST WATER PRODUCING SAND OR GRAVEL STRATA ARE UNDERLAIN AT A VERY SHALLOW DEPTH BY RELATIVELY IMPERMEABLE STRATA THAT RESTRICT THE DOWNWARD MOVEMENT OF GROUND WATER THE WATER SURFACES IN THESE AQUIFERS ARE NEAR THE GROUND SURFACE AND EXCESSIVE EVAPOTRANSPIRATION OCCURS
AREAS OF INSUFFICIENT DATA. AQUIFERS IN THE UPLAND AREAS ARE CONSIDERED TO BE CONFINED ALTHOUGH EXTENT AND CONTINUITY OF CONFINING LAYERS ARE UNKNOWN AQUIFERS IN THE MERRIT SAND IN THE VICINITY OF ALAMEDA ARE PROBABLY UNCONFINED
BAY PLAIN
LINES OF EQUAL ELEVATION OF GROUND WATER IN THE NEWARK AQUIFER OF THE NILES CONE, AND IN UNDIFFERENTIATED SHALLOW AQUIFERS OF THE SAN LORENZO AND SAN LEANDRO CONES DASHED WHERE INFERRED.
30
LINES OF EQUAL ELEVATION OF GROUND WATER IN THE CENTERVILLE AQUIFER OF THE NILES CONE AND IN UNDIFFERENTIATED DEEPER AQUIFERS OF THE SAN LORENZO AND SAN LEANDRO CONE DASHED WHERE INFERRED.
LIVERMORE VALLEY
LINES OF EQUAL ELEVATION OF GROUND WATER IN THE UPPER AQUIFER AND OTHER UNDIFFERENTIATED SHALLOW AQUIFERS DASHED WHERE INFERRED
30
LINES OF EQUAL ELEVATION OF GROUND WATER IN UNDIFFERENTIATED DEEPER AQUIFERS WEST OF THE LIVERMORE FAULT AND IN ALL AQUIFERS EAST OF THE LIVERMORE FAULT. DASHED WHERE INFERRED
BOUNDARY OF GROUND WATER BASIN
BOUNDARY OF GROUND WATER BASIN SUBDIVISION
NOTE ELEVATION IS IN FEET REFERRED TO SEA LEVEL-U S G S DATUM. NEGATIVE WHERE BELOW SEA LEVEL
STATE OF CALIFORNIA
THE RESOURCES AGENCY OF CALIFORNIA
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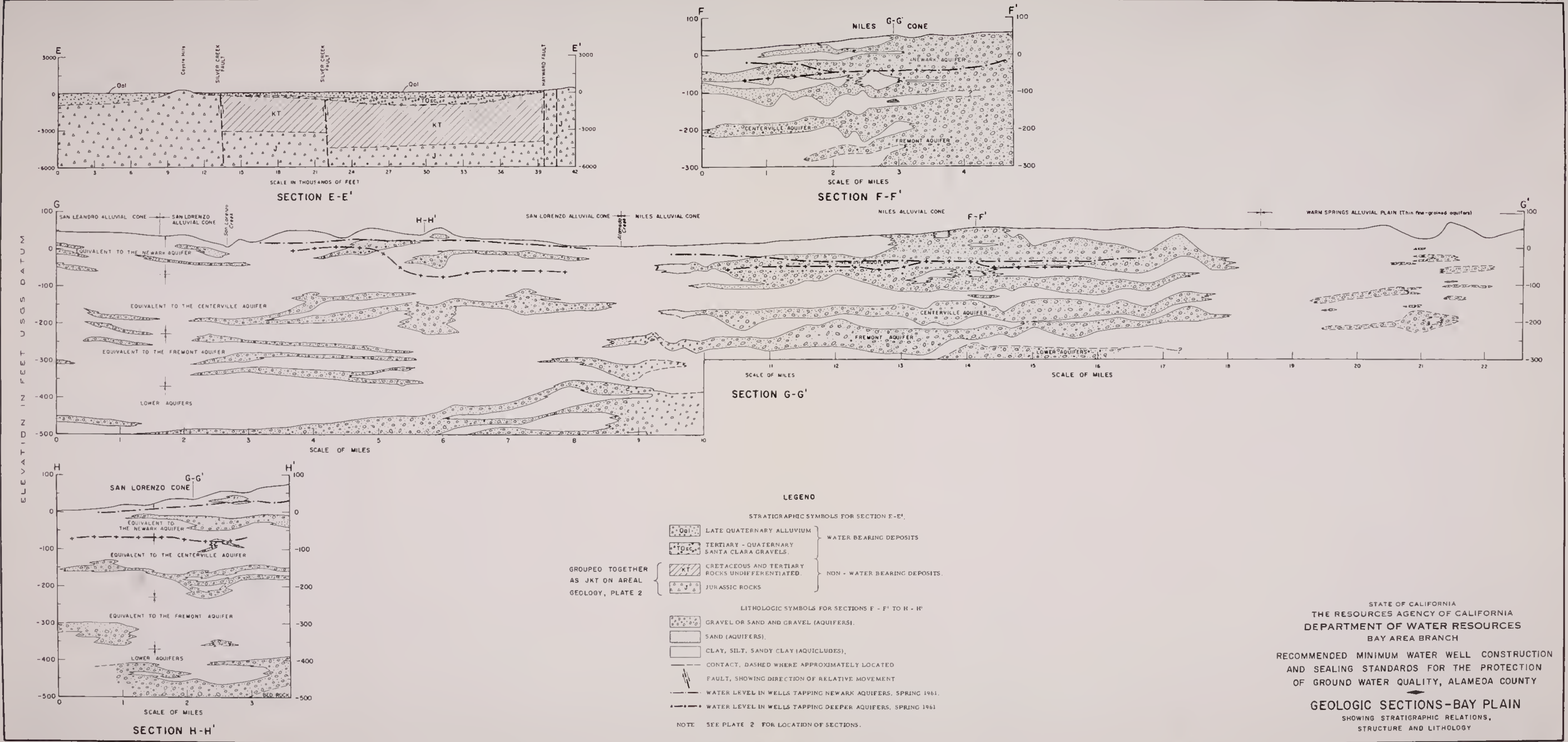
BAY AREA BRANCH
RECOMMENDED MINIMUM WATER WELL CONSTRUCTION AND SEALING STANDARDS FOR THE PROTECTION OF GROUND WATER QUALITY, ALAMEDA COUNTY
GROUND WATER CONDITIONS
AND
LINES OF EQUAL ELEVATION OF GROUND WATER
SPRING 1961
SCALE OF MILES
0
2
3
4
R 3 W
R 2 W
R 1 W
R 1 E
R 2 E
R 3 E
R 4 E
T 1 S
T 2 S
T 3 S
T 4 S
T 5 S
BERKELEY
EMERYVILLE
OAKLAND
ALAMEDA
SAN LEANDRO
SAN LORENZO
HAYWARD
Castro Valley
Lake Chabot
San Leandro Res
UNION CITY (Decoto)
UNION CITY (Alvarado)
FREMONT (Niles)
FREMONT (Centerville)
FREMONT (Newark)
Danville
Dublin
Pleasanton
LIVERMORE
Altamont
Midway
Calaveras Res
DEL VALLE RES (AUTHORIZED)
DOOLAN RES (AUTHORIZED)
CONTRA COSTA
ALAMEDA
SAN JOAQUIN
ALAMEDA
SAN FRANCISCO BAY
WATERSHED
BOUNDARY
HETCH HETCHY AQUEDUCT
SOUTH BAY AQUEDUCT
DELTA-MENDOTA CANAL
CALIFORNIA AQUEDUCT
Alameda Cr
Arroyo Mocho
Arroyo Valle
Coyote Cr
ALAMEDA DIVERSION TUNNEL
MISSION TUNNEL
N



STATE OF CALIFORNIA
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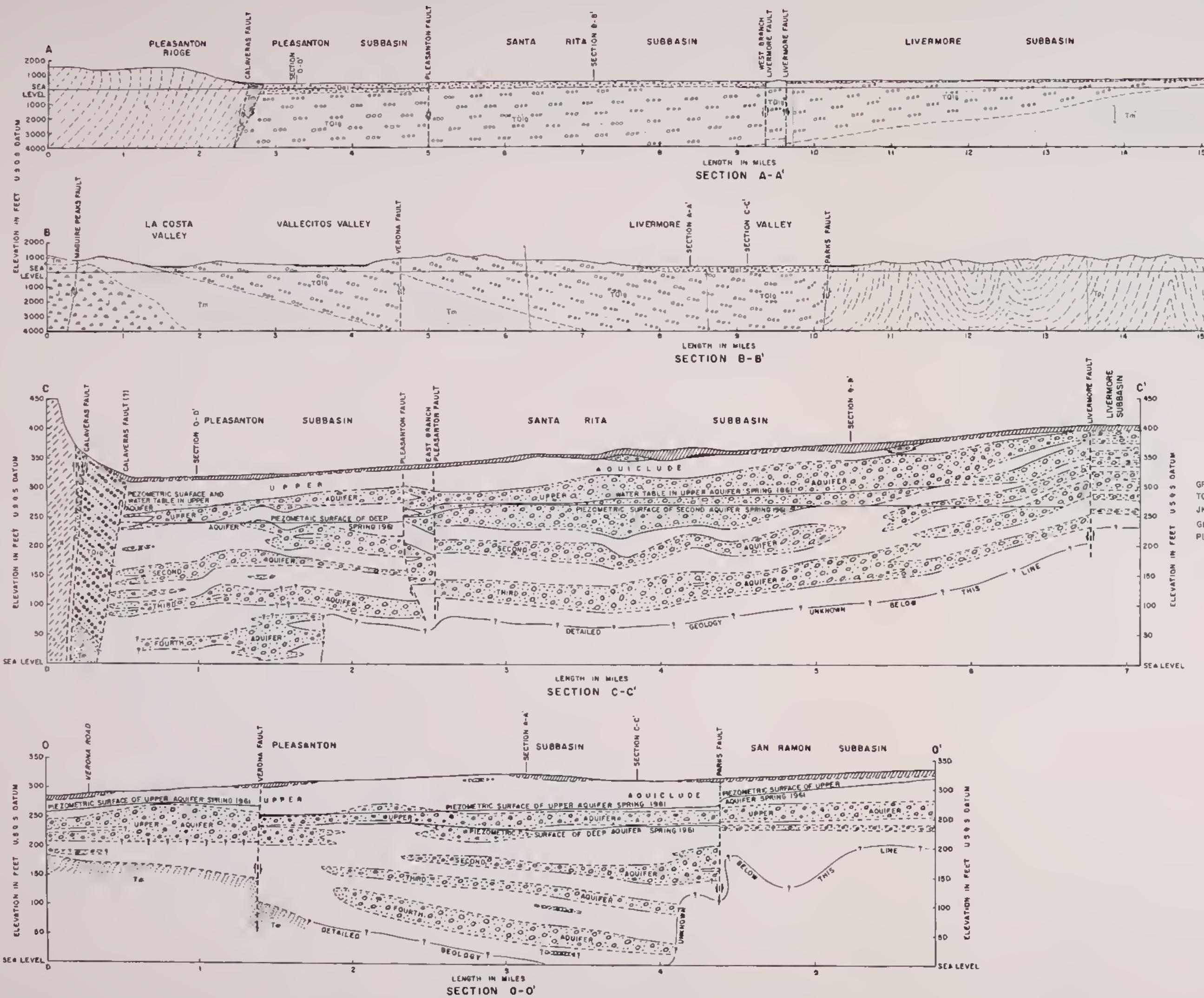
BAY AREA BRANCH

RECOMMENDED MINIMUM WATER WELL CONSTRUCTION AND SEALING STANDARDS FOR THE PROTECTION OF GROUND WATER QUALITY, ALAMEDA COUNTY

GEOLOGIC SECTIONS-BAY PLAIN

SHOWING STRATIGRAPHIC RELATIONS, STRUCTURE AND LITHOLOGY



LEGEND

STRATIGRAPHIC SYMBOLS FOR SECTIONS A-A' TO C-C'

Qal	LATE QUATERNARY ALLUVIUM	WATER BEARING DEPOSITS
TQlg	TERTIARY-QUATERNARY LIVERMORE GRAVELS.	WATER BEARING DEPOSITS
Tp	PLIOCENE DEPOSITS	NON-WATER BEARING DEPOSITS
Tm	MIOCENE ROCKS	NON-WATER BEARING DEPOSITS
K	CRETACEOUS ROCKS	NON-WATER BEARING DEPOSITS
J	JURASSIC ROCKS	NON-WATER BEARING DEPOSITS

GROUPED TOGETHER AS JKT ON AREAL GEOLOGY, PLATE 2

LITHOLOGIC SYMBOLS FOR SECTIONS C-C' TO D-D'

- SOIL
- GRAVEL OR SAND AND GRAVEL (AQUIFERS)
- SAND (AQUIFERS).
- CLAY, SILT, SANDY CLAY (AQUICLUDES).
- CONTACT, DASHED WHERE APPROXIMATELY LOCATED, QUERIED WHERE UNCERTAIN
- FAULT, SHOWING DIRECTION OF RELATIVE MOVEMENT

NOTE SEE PLATE 2 FOR LOCATION OF SECTIONS

STATE OF CALIFORNIA
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GEOLOGIC SECTIONS - LIVERMORE VALLEY

SHOWING STRATIGRAPHIC RELATIONS, STRUCTURE AND LITHOLOGY


LEGEND
LINE OF EQUAL BORON CONCENTRATION IN PARTS PER MILLION (PPM)
LINE OF 350 PPM CHLORIDE CONCENTRATION IN UPPER (NEWARK) AQUIFER OF NILES CONE (1961)
CHLORIDE CONCENTRATION IN EXCESS OF 350 PPM IN LOWER AQUIFERS OF NILES CONE (1961)
WELLS PRODUCING GROUND WATER WITH NITRATE CONCENTRATIONS IN EXCESS OF 44 PPM
WELLS PRODUCING GROUND WATER WITH CHLORIDE CONCENTRATIONS IN EXCESS OF 350 PPM (NILES CONE EXCLUDED)
ABANDONED OIL WELL
SPRING
CHARACTER OF WATER
APPROXIMATE AVERAGE TOTAL DISSOLVED SOLIDS IN PPM
CALCIUM - MAGNESIUM BICARBONATE 300
CALCIUM - MAGNESIUM BICARBONATE 400
MAGNESIUM BICARBONATE 500
CALCIUM - SODIUM BICARBONATE 550
SODIUM BICARBONATE 500
VARIABLE 650
SODIUM BICARBONATE - CHLORIDE 700
SODIUM BICARBONATE - CHLORIDE 1700
SODIUM CHLORIDE 2450
BERKELEY
EMERYVILLE
OAKLAND
ALAMEDA
SAN LEANDRO
Lake Chabot
Castro Valley
SAN LORENZO
HAYWARD
UNION CITY (Decoto)
FREMONT (Niles)
UNION CITY (Alvarado)
FREMONT (Centerville)
FREMONT (Newark)
Dublin
LIVERMORE
Pleasanton
LIVERMORE VALLEY
SAN FRANCISCO BAY
Altamont
Midway
Mountain House
Calaveras Res
DEL VALLE RES (AUTHORIZED)
PATTERSON RES
DOOLAN RES (AUTHORIZED)
HETCH HETCHY AQUEDUCT
CALIFORNIA AQUEDUCT
DELTA MENDOTA CANAL
WATERSHED BOUNDARY
R 3 W
R 2 W
R 1 W
R 1 E
R 2 E
R 3 E
R 4 E
T 1 S
T 2 S
T 3 S
T 4 S
STATE OF CALIFORNIA
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RECOMMENDED MINIMUM WATER WELL CONSTRUCTION
AND SEALING STANDARDS FOR THE PROTECTION
OF GROUND WATER QUALITY, ALAMEDA COUNTY
WATER QUALITY CONDITIONS
1957-1961
SCALE OF MILES
0 1 2 3 4